This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

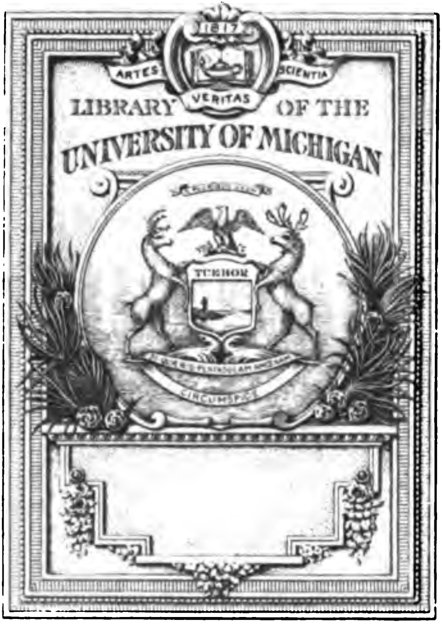
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


1817
ARTES
SCIENTIA
VERITAS
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
SI QUAERIS PENINSULAM AMOENAM
CIRCUMSPICE

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON.

GENERAL LIBRARY
University
MICHIGAN

From November 18, 1875, *to April* 27, 1876.

VOL. XXIV.

LONDON:
PRINTED BY TAYLOR AND FRANCIS,
RED LION COURT, FLEET STREET.
MDCCCLXXVI.

CONTENTS.

VOL. XXIV.

No. 164.

Page

The Bakerian Lecture.—On the Forms of Equipotential Curves and Surfaces and on Lines of Flow. By W. G. Adams, M.A., F.R.S., Professor of Natural Philosophy and Astronomy in King's College, London. (Plates 1 & 2.) 1

November 18, 1875.

Report to the Hydrographer of the Admiralty on the Cruise of H.M.S. 'Challenger' from June to August 1875. By Prof. Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff on Board. (Plates 3–7.) 33

On the Physiological Action of Vanadium. By John Priestley, Platt Physiological Scholar, Owens College, Manchester 40

On some Elementary Principles in Animal Mechanics.—No. VII. The Law of Fatigue. By the Rev. Samuel Haughton, M.D. (Dubl.), D.C.L. (Oxon.), F.R.S., Fellow of Trinity College, Dublin 42

November 25, 1875.

On the Replacement of Electro-positive by Electro-negative Metals in a Voltaic Cell. By J. H. Gladstone, Ph.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and Alfred Tribe, Lecturer on Chemistry in Dulwich College 47

On the Production of Glycosuria by the Effect of Oxygenated Blood on the Liver. (Supplement to Communication presented June 17th, 1875.) By F. W. Pavy, M.D., F.R.S. 51

On the Structure and Relations of the Alcyonarian *Heliopora cærulea*, with some Account of the Anatomy of a Species of *Sarcophyton*; Notes on the Structure of Species of the Genera *Millepora*, *Pocillopora*, and *Stylaster*; and Remarks on the Affinities of certain Palæozoic Corals. By H. N. Moseley, M.A. (*Oxon.*), *Naturalist* to the 'Challenger' *Expedition* 59

November 30, 1875.

Page

Anniversary Meeting:
- Report of Auditors 70
- List of Fellows deceased since last Anniversary 71
- ———— elected 71
- Address of the President 72
- Presentation of the Medals 89
- Election of Council and Officers 94
- Financial Statement .... 96 & 97
- Trust Funds 98–100

Account of the appropriation of the sum of £1000 annually voted by Parliament to the Royal Society (the Government Grant), to be employed in aiding the advancement of Science 101

Account of Grants from the Donation Fund in 1874–75 102

Report of the Kew Committee 102

List of Presents 115

No. 165.—*December* 9, 1875.

On some Electro-magnetic Rotations of Bar-magnets and Conducting-wires on their Axes. By G. Gore, F.R.S. 121

On the Development of *Lepas fascicularis* and the "*Archizoëa*" of Cirripedia. By R. von Willemöes-Suhm, Ph.D., Naturalist to the 'Challenger' Expedition 129

Preliminary Remarks on the Development of some Pelagic Decapods. By R. von Willemöes-Suhm, Ph.D., Naturalist to the 'Challenger' Expedition 132

December 16, 1875.

On the Development of the Spinal Nerves in Elasmobranch Fishes. By F. M. Balfour, B.A., F.L.S., Fellow of Trinity College, Cambridge 135

On the Structure and Development of the Skull in the Batrachia.—Part II. By Prof. W. K. Parker, F.R.S. 136

Preliminary Observations on the Locomotor System of Medusæ. By G. J. Romanes, M.A., F.L.S. 143

Note on the Placentation of *Hyrax*. By William Turner, M.B. (Lond.), Professor of Anatomy, University of Edinburgh 151

List of Presents 155

No. 166.—*January* 6, 1876.

On the Expansion of Sea-water by Heat. By T. E. Thorpe, Ph.D., and A. W. Rücker, M.A. (Fellow of Brasenose College, Oxford), Professors of Chemistry and Physics in the Yorkshire College of Science 159

On the Action of Light on Tellurium and Selenium. By Prof. W. G. Adams, F.R.S. 163

Page

On the Refraction of Sound by the Atmosphere. By Prof. Osborne Reynolds, Owens College, Manchester 164

On the Length of the Spark from a Battery of 600, 1200, 1800, and 2400 rod-Chloride-of-Silver Cells, and some Phenomena attending the Discharge of 5640 Cells. By Warren De La Rue, D.C.L., F.R.S., and Hugo W. Müller, Ph.D., F.R.S.. 167

January 13, 1876.

On the Optical Deportment of the Atmosphere in reference to the Phenomena of Putrefaction and Infection. By John Tyndall, F.R.S......... 171

January 20, 1876.

Certain cases of Electromotive Force sustained by the Action of Electrolytes on Electrolytes. By J. Hopkinson 183

On Reversed Photographs of the Solar Spectrum beyond the Red, obtained on a Collodion Plate. (In a Letter to Prof. Stokes.) By Captain J. Waterhouse, Assistant Surveyor-General of India 186

Report of the Meteorological Committee to the President and Council of the Royal Society on the Work done in the Meteorological Office since their appointment in 1866 to December 31, 1875 189

On the Structure, Physiology, and Development of *Antedon* (*Comatula*, Lamk.) *rosaceus*. By William B. Carpenter, M.D., F.R.S. (Plates 8, 9.) 211

January 27, 1876.

On the Variations of the Daily Mean Horizontal Force of the Earth's Magnetism produced by the Sun's Rotation and the Moon's Synodical and Tropical Revolutions. By J. A. Broun, F.R.S. 231

Results of the Monthly Observations of Magnetic Dip, Horizontal Force, and Declination made at the Kew Observatory from April 1869 to March 1875 inclusive. By the Kew Committee 232

Contributions to the Minute Anatomy of the Thyroid Gland of the Dog. By E. Cresswell Baber, M.D. Lond.................................. 240

Research on the Minute Anatomy of the Alimentary Canal. By Herbert A. Watney, M.A., Demonstrator of Microscopical Anatomy at St. George's Hospital 241

List of Presents 244

No. 167.—*February* 3, 1876.

On Formulæ of Verification in the Partition of Numbers. By J. W. L. Glaisher, M.A., F.R.S. 250

On the Development and Succession of the Poison-fangs of Snakes. By Charles S. Tomes, M.A.. 259

Page

On an Integrating Machine having a New Kinematic Principle. By Prof. James Thomson, LL.D., F.R.S.E. 262

On an Instrument for calculating $\left(\int \phi (x) \psi (x) dx\right)$, the Integral of the Product of two given Functions. By Prof. Sir W. Thomson, LL.D., F.R.S. 266

Mechanical Integration of the Linear Differential Equations of the Second Order with Variable Coefficients. By Prof. Sir W. Thomson, LL.D., F.R.S. 269

Mechanical Integration of the general Linear Differential Equation of any Order with Variable Coefficients. By Prof. Sir William Thomson, LL.D., F.R.S. 271

February 10, 1876.

On Repulsion resulting from Radiation.—Part III. By William Crookes, F.R.S. &c. 276

On Repulsion resulting from Radiation.—Part IV. By William Crookes, F.R.S. &c. 279

February 17, 1876.

Researches upon the Specific Volumes of Liquids.—II. By T. E. Thorpe, Ph.D., F.R.S.E., Professor of Chemistry in the Yorkshire College of Science, Leeds 283

Researches upon the Specific Volumes of Liquids.—III. By T. E. Thorpe, Ph.D., F.R.S.E., Professor of Chemistry in the Yorkshire College of Science, Leeds 298

Experimental Contributions to the Theory of Electrolysis. By Alfred Tribe, Lecturer on Chemistry in Dulwich College 308

Letter to the President from P. Cunliffe Owen, Director S. K. M. 315

February 24, 1876.

Letter to the President from T. J. Phillips Jodrell, Esq. 316

On determining the Depth of the Sea without the use of the Sounding-line, and on an Attraction-meter. By C. William Siemens, D.C.L., F.R.S., M.I.C.E. 317

On Instruments for Recording the Direction and Velocity of Currents and the Temperature of the Water at different Depths in the Ocean. By J. Rymer Jones, of the Imperial Government Telegraphs, Japan 321

List of Presents 330

On the Theory of the Solution of a System of Simultaneous Non-linear Partial Differential Equations of the First Order. By E. J. Nanson.... 337

No. 168.—*March* 2, 1876.

Page

List of Candidates for Election into the Society 345

The Organ of Corti in Mammals. By Urban Pritchard, M.D., F.R.C.S., Lecturer on Physiology (Evening Classes), King's College, London, Surgeon to the Royal Ear Dispensary 346

Preliminary Note on the Compound Nature of the Line-Spectra of Elementary Bodies. By J. N. Lockyer, F.R.S.............................. 352

On the Influence of Coal-dust in Colliery Explosions. By W. Galloway.. 354

March 9, 1876.

On the Diurnal Variations of the Disturbances of the Magnetic Declination at Lisbon. By J. Capello, Director of the Lisbon Observatory 373

On the Development of the Crustacean Embryo, and the Variations of form exhibited in the Larvæ of 38 Genera of Podophthalmia. By C. Spence Bate, F.R.S. 375

On a Secular Variation in the Rainfall in connexion with the Secular Variation in amount of Sun-spots. By Charles Meldrum, M.A., Director of the Mauritius Observatory 379

March 16, 1876.

'Challenger' Reports. (See No. 170.) 387, 388

March 23, 1876.

On the Force caused by the Communication of Heat between a Surface and a Gas, and on a New Photometer. By Prof. Osborne Reynolds........ 388

On the Nature of the Force producing the Motion of a Body exposed to Rays of Heat and Light. By Arthur Schuster, Ph.D., Demonstrator in the Physical Laboratory of Owens College.......................... 391

On the Number of Figures in the Period of each Reciprocal of a Prime from 53,000 to 60,000. By W. Shanks 392

On a new Refractometer for measuring the Mean Refractive Index of Plates of Glass and Lenses by the employment of Newton's Rings. By G. W. Royston-Pigott, M.A., M.D. Cantab., F.R.S., F.R.A.S., F.C.P.S. 393

Description of a Mammalian Ovum in an early condition of Development. By Edward Albert Schäfer, Assistant Professor of Physiology in University College, London. (Plate 10.) 399

'Challenger' Report. (See No. 170).................................. 403

March 30, 1876.

Page

An Experiment on Electro-Magnetic Rotation. By W. Spottiswoode, M.A., Treas. and V.P.R.S. 403

The Residual Charge of the Leyden Jar. By J. Hopkinson, M.A., D.Sc... 407

On the Placentation of the Lemurs. By Wm. Turner, M.B. (Lond.), Professor of Anatomy, University of Edinburgh 409

On the Movement of the Glass Case of a Radiometer. By William Crookes, F.R.S. &c. 409

List of Presents 410

Preliminary Note on the Anatomy of the Umbilical Cord. By Lawson Tait, F.R.C.S. &c. (Plates 11–14.) 417

No. 169.—*April* 6, 1876.

Experiments on the Friction between Water and Air. By Dr. Ritter von Lang 441

An Inquiry into the Cause of the slow Pulse in Jaundice. By J. Wickham Legg, M.D., Demonstrator of Morbid Anatomy in St. Bartholomew's Hospital 442

On the Structure of a Species of *Millepora* occurring at Tahiti, Society Islands. By H. N. Moseley, M.A., Naturalist to the 'Challenger' Expedition 448

Supplemental Note to a Paper on the Structure, Physiology, and Development of *Antedon* (*Comatula*, Lamk.) *rosaceus*. By William B. Carpenter, M.D., F.R.S. 451

April 27, 1876.

The Bakerian Lecture.—On the Gaseous State of Matter. By Prof. T. Andrews, LL.D., F.R.S., Vice-President of Queen's College, Belfast.... 455

List of Presents 459

No. 170.

Preliminary Report to the Hydrographer of the Admiralty on some of the Results of the Cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso. By Prof. Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff on Board. (Plates 15–19.) 463

Preliminary Reports to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work done on board the 'Challenger.' By John Murray, Esq., Naturalist to the Expedition. (Plates 20–24.).. 471

Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on the true Corals dredged by H.M.S. 'Challenger' in deep water between the dates Dec. 30th, 1870, and August 31st, 1875. By H. N. Moseley, Naturalist to the Expedition 544

Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Observations made during the earlier part of the Voyage of H.M.S. 'Challenger.' By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition 580

Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Crustacea observed during the Cruise of H.M.S. 'Challenger' in the Southern Sea. By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition....................... 585

Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work (Chemical and Geological) done on board H.M.S. 'Challenger.' By J. Y. Buchanan, Chemist and Physicist to the Expedition 593

Report to the Hydrographer of the Admiralty on the Voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a Position in lat. 32° 24′ S., long. 13° 5′ W. By Prof. Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff on board. (Plates 25–33.) 623

Index 637

Obituary Notices of Fellows deceased :—

Sir William Edmond Logan.............................. i
Daniel Hanbury ii
Gustav Rose iii
Christopher Hansteen v
Charles Eugène Delaunay............................... vii
Thomas Hewitt Key x
Sir Charles Wheatstone xvi
Justus Liebig xxvii
Auguste Arthur de la Rive xxxvii

ILLUSTRATIONS.

Plates 1 and 2 illustrating Prof. W. G. Adams's Paper on the Forms of Equipotential Curves and Surfaces and on Lines of Flow.

Plates 3–7 illustrating Prof. W. Thomson's Report on the Cruise of H.M.S. 'Challenger' from June to August 1875.

Plates 8 and 9 illustrating *Dr. W. B. Carpenter's* Paper on the Structure, *Physiology, and Development of Antedon rosaceus.*

Plate 10 illustrating Mr. E. A. Schäfer's Paper on a Mammalian Ovum in an early condition of Development.

Plates 11–14 illustrating Mr. L. Tait's Paper on the Anatomy of the Umbilical Cord.

Plates 15–19 illustrating Prof. W. Thomson's Report on some of the Results of the Cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso.

Plates 20–24 illustrating Mr. J. Murray's Reports on Work done on board H.M.S. 'Challenger.'

Plates 25–33 illustrating Prof. W. Thomson's Report on the Voyage of H.M.S. 'Challenger' from the Falkland Islands to Monte Video &c.

OBITUARY NOTICES OF FELLOWS DECEASED.

Sir **William Edmond Logan** was born at Montreal on the 20th of April, 1798. His education was commenced at Montreal, where he remained until, in 1814, he was sent to the High School of Edinburgh. In 1818 he was taken into the house of his uncle, Mr. Hart Logan, a merchant in London; but, in 1829, after a short visit to Canada, he accepted the management of a copper-smelting work at Swansea.

His attention was soon attracted to the geology of the district, especially to the Coal-measures of the great South-Wales Coal-field, of the western half of which he constructed, entirely at his own cost, a geological map, on the scale of 1 inch to a mile, with horizontal sections on a scale of 6 inches to a mile, and vertical sections on a scale of 40 feet to an inch. While engaged in this work he discovered the true relation of the clays charged with Stigmaries underlying each bed of coal, and proved them to be the soil on which the plants, afterwards turned into coal, had grown. In 1840 he communicated this discovery to the Geological Society. This work was so completely and accurately executed, that when Mr. De la Beche began the Government Geological Survey of that area he adopted the whole of it, which Mr. Logan generously handed over to him for the benefit of the Survey; and the sections became in a measure the models on which all the Coal-measure sections of the Survey were afterwards constructed. Having given up his connexion with the copper-works, Mr. Logan was appointed by the Colonial Government, in 1843, to organize and carry on a Geological Survey of Canada, his native country, with which his family had long been connected; and this work, by his own labours and the help of his assistants, he carried on as Director of the Survey till the year 1869, when, in consequence of increasing years, he resigned the appointment, and Mr. Selwyn, now one of the Fellows of this Society, was appointed as his successor. The admirable geological work that he did in Canada, and the beautiful geological maps and sections thereby produced, are well known to the geological world; for he not only unravelled and laid down on maps all the complicated Devonian, Silurian, and Huronian rocks of a vast region, but he first discovered underneath all these the true stratigraphical relations of the Laurentian series, which had previously been vaguely termed granites. He thus showed that they consisted of two great divisions, the Lower Laurentian gneiss and the Upper Laurentian gneiss, which lies quite unconformably on the lower series, both of them containing thick interstratified beds of crystalline limestone.

While engaged in this work he discovered, in one of the bands of limestone belonging to the Lower Laurentian series, the oldest known fossil, *Eozoon canadense*, the structure of which has since been made the subject of elaborate memoirs by Dr. Dawson, of Montreal, and Dr. Carpenter, who consider it to belong to the Foraminifera. The subject was and is of high importance in geology, and at the time of the discovery excited much interest among geologists and biologists.

In 1851 Mr. Logan was elected a Fellow of the Royal Society: in 1856 the honour of knighthood was conferred on him, in recognition of his great services to geology; and the award of the Wollaston Medal by the Geological Society, in the same year, and of a Royal Medal by the Royal Society in 1867, marked the esteem in which his scientific achievements were held. Among other distinctions he was LL.D., F.G.S., and Vice-President of the Natural-History Society of Montreal.

Sir William Logan died on the 22nd of June, 1875, at Castle Malgwyn, in the house of his sister, Mrs. Gower, in his 77th year; and it may truly be said of him that no man was ever more esteemed and beloved by a numerous circle of friends.

By the death of DANIEL HANBURY the Society has lost a very learned and highly cultivated pharmacologist, who had for some years occupied one of the first places among the scientific men of Europe. Besides advancing the science of pharmacy by his numerous writings, he led the way in promoting a scientific education among druggists, in conducting examinations in London which greatly improved their status, in promoting the welfare of the Pharmaceutical Society, and in organizing those pharmaceutical conferences, of which he was twice the President, that meet annually at the time and place of meeting of the British Association.

Mr. Hanbury will be best known to posterity by the work, brought out shortly before his death by Dr. Flückiger and himself, entitled "Pharmacographia: a History of Drugs," which may be regarded as a monument of his profound knowledge and great capacity. His published papers, more than sixty in number, dating from 1850, are all original investigations into the origin, history, botanical and chemical characters, names, uses, and commercial value of drugs; and it may be said of them that, in point of accuracy and scientific method, they are perfect. Hence but few readers have ventured to criticise his statements, so well and widely known was his caution and his mastery of all the subjects on which he wrote.

Nor were his scientific labours confined to the library and laboratory; he travelled much, not for commercial objects, but in pursuit of pharmaceutical information, and always with one definite object of inquiry, to which all others were subsidiary. He journeyed in Syria with Dr. Hooker in 1860, and made many visits to Middle and Southern

France and the Mediterranean, during which he formed an extensive acquaintance with men of science and foreign institutions, and with the contents of their museums, libraries, botanic gardens, and drug-stores; and he contemplated, for the same purpose, a visit to India, which, but for his untimely death, would have been undertaken, for he was a man who never spoke of intentions which he had not predetermined to fulfil.

Mr. Hanbury was born on September 11, 1825, and was the eldest son of Daniel Bell Hanbury, Esq., of the firm of Allen, Hanburys, and Barry, of Plough Court, Lombard Street, of which firm Daniel was himself a partner till a few years before his death, when he retired to devote himself to the favourite pursuit of his life. To his other accomplishments he added the skill of a water-colour artist, and his works are distinguished by accuracy of drawing and truthfulness of colouring. He was familiar with several European languages, was a facile manipulator, distinguished for the completeness of his collections, the perfection of his pharmaceutical museum, and the amount of information embodied in the notes that accompanied his own specimens and those he so liberally distributed to scientific institutions and individuals. He was a member of the Society of Friends, a Fellow and Treasurer of the Linnean Society, in which he took an active interest, and a Fellow of the Chemical Society. He was elected a Fellow of the Royal Society in 1867, and was a member of its Council at the date of his death, which took place at Clapham, March 24, 1875, of typhoid fever, supervening on an attack of inflammation.

Gustav Rose, born on the 18th of March, 1798, was the youngest of the four sons of Valentin Rose, Assessor of the Ober Collegium Medicum at Berlin, and brother of the illustrious chemist, Heinrich Rose. He lost his father early. An excellent mother guided the education of the four sons, whose youth fell in a hard and laborious time. All four brothers served their country in the war of liberation. Gustav, only seventeen years old at the time of the battle of Waterloo, was not in any engagement, but made the long march under arms from Berlin to Orleans. He began life as a mining engineer, but was attacked by an inflammation of the lungs. The scientific pursuits to which he devoted himself during his recovery, as well as the intercourse with his brother Heinrich, induced him to give up his engineering pursuits and to devote himself entirely to science. He went to Stockholm and worked under Berzelius. In 1826 he was appointed Extraordinary Professor of Mineralogy, and in 1839 Ordinary Professor at Berlin, and, after the death of Weiss, Director of the Royal Mineralogical Museum at Berlin. For the sake of making scientific observations he travelled through a wide expanse of country—Scandinavia, England and Scotland, Italy and Sicily, France and Austria. In the year 1829 *he travelled with Von Humboldt* and Ehrenberg to the

Ural, the Altai, and the Caspian Sea and the boundary of China. This journey laid the foundation of the knowledge of the Mineralogy of the extensive Russian Empire. His researches in Germany were devoted to the Silesian mountains.

G. Rose was the first in his own country who determined accurately the angles of crystals with the aid of the reflecting goniometer. He took an important part in the labours which led Mitscherlich to the discovery of isomorphism. His labours embrace every department of Mineralogy—crystalline forms and their combinations, the physics of crystallography, the chemical composition and the artificial production of minerals, and the art of crystallographic drawing. The knowledge of the association of minerals in rocks (petrography) was founded by him, as he was one of the first who taught how, with the aid of the microscope, to investigate the minerals invisible to the eye in a very thin polished plate of stone.

He applied himself with especial delight to the study of Meteorites, those wonderful bodies which fall on the earth out of the depths of space. The structure of the iron meteorites, the mineralogical constitution of the stony meteorites revealed themselves to his acute research. His mind busied itself perpetually with the extraordinary difference between the formation of the stony matter in those cosmic masses and in the solid crust of the earth. It is truly remarkable that his most beautiful mineralogical discoveries were not made in operating upon rare minerals, but upon such as exist in all collections, and of which many have been exposed to observation before. To these belong the distinctions of the forms of quartz and its various twins; the crystallization of pyrites, sought after by many in vain. The secret of making such discoveries consisted in this, that he never sought after the form alone, but always contemplated the totality of the physical appearances. During the last year of his life his inquiring thoughts were especially directed to the diamond. Few mineralogists are capable of conjecturing that the diamond in its form yet exhibits perplexities. So occupied was he with this problem, that he dictated to one of his sons the results of this last intellectual labour only four-and-twenty hours before his end.

He saw his best friends and truest companions of his labours, Mitscherlich, Magnus, Haidinger, and above all his brother Heinrich, called away from their work. Their departure and his increasing solitude filled him with sorrow. Yet he derived consolation from the reflection how much science had been promoted by his departed friends. In the year 1870 he celebrated his Doctor's Jubilee, having in this year completed the half century of his teaching career. He never sought distinction, though many honours fell to his share. When created a Knight of the Order "Pour la Mérite," the honour appeared to him to be almost too great. Imperishable is the remembrance which Gustav Rose has left behind him in Science; though not imperishable yet more touching is the remembrance which he has left behind him in the hearts of all with whom he was acquainted. In his science and in the many sided relations of his life he had no enemy, no opponent. To live in peace and friendship, which is often difficult for the best, was to him inevitable. As his own efforts were always directed to truth and goodness, he assumed the same to be the case with others. In their efforts he saw nothing but good. When the deeds or words of others failed to meet his approbation, he could not suppose there was a dishonourable motive for their conduct. This explains the fact that those who lived at variance with one another united in respecting him. On the 11th of July, 1873, he gave a lecture. Notwithstanding great weakness he wrote a long scientific letter in the evening, and concluded with the words, "Rest will do us good: we will go again to our old quarters at Friedrichshafen; would we were there!" Scarcely had he ended the letter when he was attacked by a fit of shivering, an indication of an inflammation of the lungs, which in less than four days, on the 15th of July, closed his life, in the 76th year of his age.

Gustav Rose took an active part in the foundation of the "Deutsche Geologische" Society, of which he was President from the year 1863 until his death; and almost every volume of the 'Zeitschrift' of that Society contains papers by him. Besides his works, 'Mineralogisch-geognostische Reise nach dem Ural dem Altai und dem Kaspischen Meere' (of which the first volume appeared in 1837 and the second in 1842, the result of his observations in those regions), his 'Elemente der Krystallographie,' and his 'Krystallochemische Mineralsystem,' he was the author of numerous papers published in Gilbert's and in Poggendorff's 'Annalen,' in the 'Abhandlungen' of the Berliner Akademie der Wissenschaften, and other periodicals.

CHRISTOPHER HANSTEEN was born at Christiania on the 26th September, 1784. He attended the Cathedral school of that city; and in the year 1802 he entered the University of Copenhagen, where he studied first law and afterwards mathematics. In 1806 he became a teacher of Mathematics in the Gymnasium of Fredericksburg in Zealand. It was in the year 1807 that he began to take an interest in terrestrial magnetism; and in 1812 he obtained the prize from the Royal Danish Academy of Sciences for his answer to the following question:—"Is it necessary, in order to explain facts in the earth's magnetism, to suppose more than one magnetic axis in the earth?"

In the year 1814 he was appointed to the chair of Astronomy and Applied Mathematics in the University of Christiania, founded by Frederick IV. of Norway.

In 1819 he published, at the expense of the King, his greatest work, 'Untersuchungen über den Magnetismus der Erde,' in a quarto volume of 650 pages. It was illustrated with copper plates and an Atlas of magnetic charts, and also contained an abstract of the history of the subject. This work was only preparatory to his great object. He wished to make a mathematical analysis of all the observations in the light of Euler's theory of magnets; and he strove to test Halley's speculations as to the existence of four magnetic poles in the earth, and to give a satisfactory answer to the critical problem presented by the Danish Academy of Sciences.

His Declination chart for 1787 was more accurate and full than similar charts already published by Halley, by Mountain and Dodson, and by Churchman.

He decided that there were two magnetic poles in the northern and two in the southern hemisphere; and he inferred from the secular changes in these lines that the northern magnetic poles were moving obliquely towards the east, and those in the south towards the west. He calculated approximately the period of complete revolution for each pole, and called attention to the following coincidence, namely, that the shortest time in which all the poles will return to the same relative position agreed closely with the period of revolution in the precession of the equinoxes.

By the liberality of the Norwegian Government he was enabled to go to Siberia, in company with Duc and Erman, to search for the ideal point of the Asiatic Pole of Magnetism. They started from Berlin on the 25th of April, 1828, and reached Kiachta and Irkoutsk. The Russian Government offered every facility for the success of the expedition, and the results were important. Ten magnetic observatories were established in the Russian Empire by the recommendation of Humboldt, and great results were obtained by Gauss, Sabine, Lamont, and others from the materials collected by Hansteen and Erman. Hansteen ascertained beyond dispute the existence of a magnetic pole in Siberia supplementary to that in British America, and also the biaxial character of the earth's magnetism.

Hansteen's elaborate treatise on Terrestrial Magnetism contains a discussion on the Isoclinic and Isodynamic lines, and on those of Declination. His Magnetic Atlas contained maps of dip and intensity.

These observations have of course up to the present time been added to in so far as the increased number of observations in the Arctic and Antarctic regions, in the United States of America, and at the numerous magnetic observatories have supplied more accurate and abundant data. The work has been described as a monument of industry, learning, and mathematical skill.

Soon after his Siberian expedition Hansteen prevailed upon the Norwegian Government to erect in Christiania an observatory fitted up for Magnetic Observations, and he was appointed Director of this Institution.

Hansteen reaffirmed the Decennial period as the result of 25 years of observation in Christiania, changing it, however, from 10 years to 11·33; and the coincidence between this period and that of the solar spots has since been reestablished by Wolf, who, after prolonged attention to the subject, proved the spot-period to be a little over 11 years. In 1837 the Trigonometrical and Topographical Survey of Norway was commenced, and Hansteen was placed at the head.

In 1856, when he had completed his 50th year as a teacher of Science, his jubilee was celebrated, and a medal struck in commemoration of it.

In the year 1861 he retired from active work. His great work was translated into German soon after its publication; and he also made various contributions in that language to Schweigger's 'Journal,' to Poggendorff's 'Annalen,' and to the 'Astronomischen Nachrichten.'

He published some valuable contributions to Meteorology and Astronomy.

He was a member of the American Academy of Arts and Sciences, of the Academies of Paris, Berlin, and St. Petersburg, and a foreign member of the Royal Society.

His death took place on the 11th of April, 1873.

Charles Eugène Delaunay was born at Lusigny, in the Department of the Aube, in the year 1816. He studied at the École Polytechnique, of which school he became a distinguished pupil. In the year 1836 he joined the École des Mines. While there he wrote several reports on the Coal-seams of the Valley of St. Etienne and Creusot, as well as on the principal iron and steel works of France, which were remarkable for clearness of thought and skill in theoretical speculations; and he was still a pupil in the School when a proposal was made by his former masters at the École Polytechnique that he should be appointed as Teacher of Geodesy in their school. There were difficulties in the way of this; but the anxiety to obtain the benefit of the talents of young Delaunay was so great that the Council of the school, at the head of which was M. Cordier, gave their sanction to the arrangement, and Delaunay was appointed. He subsequently became a Professor in the École Polytechnique, and later on also in the École des Mines. From the year 1845 to 1850, Delaunay held a Professorship in that section of the École des Mines which was specially devoted to the instruction of Engineers, whether attached to the Corps des Mines or those connected with the mining industry of France. He had classes for descriptive Geometry, Stereotomy, Machine drawing, Analytical Mechanics, and Elementary Physics, and his teaching is said to have been most successful. In 1850 Delaunay attached himself exclusively to the École des Mines. He was appointed to successive grades in the Corps des Mines, and became Engineer in Chief in 1858. In 1867 he was raised to the first class of his rank.

His first memoir, "Sur la Distinction des Maxima et des Minima dans les questions qui dépendent de la Méthode des Variations," was published in 1841. Other important works followed it, on the Theory of the Precession of the Equinoxes, Theory of the Motion of the Moon, elementary treatises on Astronomy and Mechanics, and many miscellaneous papers in the 'Comptes Rendus,' 'Connaissance des Temps,' and in the Journal of the École Polytechnique. He was also the author of some excellent elementary books on astronomy and mechanics. Soon, however, his attention became engaged by astronomical questions, and before long he was entirely absorbed by them. He published an important treatise on the Theory of the Tides, and about the same time the question of the Lunar Theory began to occupy him.

His greatest work, 'La Théorie de la Lune' (the first part of which occupied him fourteen years), was published in 1860 as an entire volume of 'Mémoires' of the Académie des Sciences. It made his name famous among astronomers. In 1862 the Royal Astronomical Society of London elected him one of their Associates; and in February 1870 Professor J. C. Adams presented to him, in the name of the President, the Gold Medal of the Society, in acknowledgment of the high opinion of his work entertained by English astronomers.

During the same time he published a number of papers relating to the theory, one in particular on the secular acceleration of the mean motion of the moon, which was then a subject of much controversy.

The second volume of his 'Théorie' appeared in 1867. The preparation of the Lunar Tables necessary for the completion of the work was undertaken by the Bureau des Longitudes, under the direction of Delaunay. A government grant of funds was obtained for the purpose, and the tables were in course of preparation at the time of his death. It was uncertain whether the calculations were sufficiently advanced to be carried on without him; but M. Puiseau, Member of the Bureau des Longitudes, says, "Quoique l'auteur ne soit plus là pour y mettre la dernière main, il ne sera sans doute pas impossible de terminer ce monument scientifique. Espérons pour la gloire de l'astronomie française que ce service sera rendu à la science, que ce suprême hommage ne manquera pas à notre illustre confrère."

In the year 1854, when the administration of the observatory of Paris was separated from that of the Bureau des Longitudes, several of the members of its staff retired to a house in the Rue Notre Dame des Champs, where they established a small observatory. Delaunay occupied an apartment in the same house, and there he formed a life-long friendship with Mathieu and Laugier. It was there that he worked out most of his researches, seldom going out except to give his lessons at the École des Mines or the Sorbonne. He often began work as early as five in the morning, and invariably continued until late in the evening. From this tranquil life he was called away in 1870 by the Emperor Napoleon the Third to succeed M. Leverrier as Director of the Paris Observatory. Many alterations and improvements had taken place in the Observatory since the death of Arago, and Delaunay soon became convinced of their importance. But he had not long been installed in his new office when the terrible war between France and Germany broke out; and his whole time and attention were soon absorbed in the preservation of the observatory from the effects of a bombardment. All the delicate instruments were dismantled and stowed away and the observations suspended. On the restoration of peace the observatory was soon restored to order and the observations were resumed.

Feeling the great want of public and private observatories in France, Delaunay, in conjunction with Leverrier, made an application to the government for the establishment of a certain number of geodetical and astronomical stations in different places. The observatories were to be established according to plans arranged by Delaunay and the Bureau des Longitudes.

To Delaunay is owing the independence of the Observatory of Marseilles, which had hitherto been in connexion with the Paris Observatory, also the foundation of one at Toulouse and the plan for one at Besançon. His energies were devoted to making the Observatory of Paris the great centre of astronomy in France. Shortly before his death he remarked, "We are going to do many things. The Observatory intends to devote all its energies to the reobservation of Lalande's Catalogue, to continue the ecliptic star-charts commenced by Chacornac, to observations of double stars; and, finally, we are making preparations for new determinations of the longitude of Brest, Greenwich, and Neufchâtel."

He continued his observations of the minor planets during the second half of the lunation with great success, excepting during the siege.

Delaunay lost his wife a few years after his marriage. He has left one son, who is guardian of the Forests of Vitry le Français. His aged mother, to whom he had been a most devoted son, survived him.

It remains only to relate the painful circumstance of his death. On Tuesday, July 30th, 1872, he left Paris in company with his cousin M. Millot, Controller of the Post, for a few days holiday. On the following Sunday he wrote from Bayeux that he intended spending a few days at Cherbourg, and should return to Paris on the following Thursday. On the Tuesday following a telegram was received in Paris announcing that he and his cousin and two boatmen had been drowned by the upsetting of a pleasure-boat in the roadstead of Cherbourg. It is a singular fact that both his father and brother perished by drowning.

Delaunay was a member of the Académie des Sciences of the Institute of France, and towards the close of his life had occupied the Chair. He was a Doctor of Science, a member of several learned societies, and was elected a foreign member of the Royal Society in 1869.

Thomas Hewitt Key was born in London on the 20th of March, 1799. He was the youngest son of Dr. Key, a London Physician, and half-brother of Charles Aston Key, the eminent surgeon.

T. H. Key was sent to the Rev. Samuel Dewe's school at Buntingford in Hertfordshire, where he remained nearly ten years. From this school he went to St. John's College, Cambridge; but he removed to Trinity College, Cambridge, during his undergraduateship, and obtained a scholarship in his new college. He took his degree in 1821, and was nineteenth wrangler.

Mr. Key's inclination was to go to the bar; but in compliance with the wish of his father, to whom he was a most dutiful and affectionate son, he began to prepare for the medical profession, and he studied nearly two years at Guy's Hospital; but his purpose was changed by the acceptance of the Professorship of Mathematics in the University of Virginia, U.S., under the following circumstances. In the summer of 1824 an agent from the State of Virginia came to England to choose four professors for the new University of Virginia, which had been established by the Legislature at Charlottesville in a central position in the State, and near Monticello, the residence of Mr. Thomas Jefferson. The course of instruction was planned by Mr. Jefferson, himself a Virginian, and once President of the United States. He was the Rector of the new University, and even the architect, though he was then past eighty years of age. He also made out a catalogue of valuable books for the university library, and the agent was empowered to purchase the books in England. Mr. Jefferson, as Rector and head of the Board of Visitors, superintended the affairs of the University till his death in 1826. In the simple inscription which he left for his tomb on the hill named Monticello, he describes himself as "the author of the Declaration of Independence, the act for Religious Toleration, and the Rector of the University of Virginia." The Presidency of the United States is not mentioned. Mr. Jefferson thought that it was a greater honour to have been the active founder of a University in his native State; and he expected that it would be a great benefit to the country. Fifty years of experience have confirmed his expectations, and the University of Virginia is now a valuable school.

Mr. Key before leaving England married Miss Sarah Troward, daughter of Richard Ironmonger Troward, who was solicitor for the prosecution in Warren Hastings's trial. This happy marriage continued to his death, and he had the rare felicity of celebrating his golden wedding on the 28th of September, 1874.

In Virginia Mr. Key was a successful teacher of mathematics, a science for which he had a great natural capacity, and he was much beloved by his pupils. In the summer of 1825, during the absence of the Professor of Ancient Languages, Mr. Key, in addition to his own classes, taught the Greek and Latin classes in the University. He left Charlottesville in 1827 much regretted, and returned to London. During his residence in Virginia he began his etymological study of the Latin language, which he prosecuted to the end of his life.

In 1828 he was appointed Professor of Latin in the University of London in Gower Street. The University of London was opened on the 1st of October, 1828. An attempt was made to establish in Gower Street a school in connexion with the new University for supplying it with well-prepared pupils. The design was good, but the school did not promise much success. In 1833 this school, or a school in place of it, was established in the University buildings in Gower Street, and Mr. Key, the Professor of Latin, and Mr. Malden, the new Professor of Greek, were appointed joint head masters. In 1842 Mr. Key gave up the Professorship of Latin and took the Professorship of Comparative Grammar with the undivided headship of the school, which he held to the day of his death. Professor Malden still continued to teach the sixth Greek class in the school till recently.

In 1836 the present University of London was established, and the University of London in Gower Street received a Royal Charter, and took the name of University College, which it now has. This Charter was annulled by Act of Parliament of the 24th of June, 1869, whereby the College was reincorporated with additional powers, and divested of its proprietary character.

The school of University College has been a good place of education under the two original head masters and the subsequent head mastership of Mr. Key only. It has given a more enlarged and useful education for boys than could be got at most schools; and one proof of success is the number of able men who have been brought up in it and are now well known in the world. For some years the number of boys was not large, but there was a steady increase. In 1868 the number was about four hundred, and in 1875, the last year of Mr. Key's life, it was above six hundred.

Mr. Key was employed from 1828 till his death in November 1875 as a teacher and head master in University College School, and also, first, as Professor of Latin and afterwards of Comparative Grammar in University College. He was the first Professor of Comparative Grammar in the College, and it will be very difficult to supply his place. It is stated in the Report of the Council, February 23rd, 1876:—"Since 1842, when Mr. Key was appointed to the Professorship of Comparative Grammar, the science of Philology has been more generally studied than had previously been the case; and there can be no doubt that the increased interest with which the subject is now regarded is to some extent attributable to the zeal with which he devoted himself to his professorial duties, and to the extensive erudition which he displayed in lecturing on the subject in which he took an enthusiastic interest, which gave to his lectures a charm rendering them most attractive, and communicating his enthusiasm to many of the *students.*"

A few words must be added on other matters, in which Mr. Key's active mind and great abilities enabled him to do much service to his country in other ways. He was like the Roman in one respect of whom C. Cæsar said, "Whatever this man wills, he wills it with all his might." He was a zealous and efficient supporter of the Reform Bill for the improvement of the constitution of the House of Commons, of the Bill for the repeal of the Corn Laws, and of the Bill for the repeal of the duty on paper; and he also took an active part in the elections for Marylebone when Admiral Charles Napier was elected. Mr. Key was one of the founders of the London Library in St. James's Square and a member of the Committee, and also a member of the Society for the Diffusion of Useful Knowledge. He was until a few years before his death a regular attendant at the meetings of the Philological Society of London, and for some years President of the Society. His contributions to the Proceedings of this Society were numerous: there is a list of them in the preface to his Philological Essays (1868). He was one of those who assisted in originating the formation of the body of Volunteers; but he lived long enough to think that the country was trusting too much to the Volunteers, and that it required other and more complete defence.

Mr. Key was an acute observer of facts, and he possessed in a remarkable degree the power of judging of evidence and of character, as he showed in the case of Lord Cochrane, afterwards Earl of Dundonald, one of the greatest seamen that this country has produced. Lord Cochrane, with his uncle Cochrane Johnston, was tried in 1814 for conspiracy and fraud, unjustly convicted, and disgraced. In 1847, when Lord Dundonald was not yet fully restored, Mr. Key was led to read the report of the trial, and from a careful examination of the evidence, he was convinced of Lord Dundonald's innocence. At this time he became acquainted with Lord Dundonald, and he has left many papers which he received from him. Mr. Key had the satisfaction at last of seeing the veteran seaman restored to all his honours and his great name cleared from an unmerited stain.

In 1856 Mr. Key wrote an excellent pamphlet on the division of profits in the London Life Association, in which he was one of the insured. He showed here his capacity to deal with problems of life insurance, and powers which would certainly have raised him to eminence as a lawyer. The changes which he recommended were not made at the time, but they have since been substantially adopted, to the great benefit of the members of the Association.

Mr. Key's literary labours will be briefly noticed. He made a good map of ancient France (Gallia) for the Useful Knowledge Society's Atlas. This map was accompanied by a map of France in Provinces, as they existed before the Revolution of 1789. He was very fond of geography, and taught it well in the school of University College. He wrote several articles in the Journal of Education of the Useful Knowledge Society, among which was a review of an English translation of Zumpt's Latin Grammar, and of the school editions of Terence, with remarks on the metres of Terence. In the review of Zumpt's Grammar he made the first proposal, as far as he knew and as far as the writer knows, to apply the crude-form system of the Sanskrit Grammarians to the classical languages; and he says (Appendix I. Key's Latin Grammar, edition of 1858), "The system had been previously expounded in the classical lecture-rooms of the University of London" (now University College)*. In 1829 Mr. Key had attended the Sanskrit class of the learned Dr. Rosen in the then University of London; but he had never time to prosecute the study of Sanskrit beyond the elementary part.

Mr. Key contributed to the Penny Cyclopædia of the Useful Knowledge Society some valuable articles, chiefly on Language. Among them were articles on the letters of the Alphabet, the article on the Alphabet, and one on the metres of Terence. These papers were for the most part collected in a little volume (1844), and there was prefixed to it a Prefatory Letter to his colleague, the Professer of Latin in University College. This Prefatory Letter gave rise to a controversy. Those who are curious about the matter will find further information on it in the Preface to Mr. Key's Philological Essays.

In 1846 Mr. Key published a Latin Grammar on the system of Crude Forms, and in 1862 what he says he may call a third edition of the same, "corrected and somewhat enlarged." In 1846 few Latin scholars knew what crude forms were. The book was used in University College School, but the teaching of Latin and Greek on this system had been a long time practised there. The book sold slowly, for no persons are slower in making improvements in education than the common teachers of Latin. In Appendix I. to the Grammar Mr. Key has explained the Crude Form, upon which system, as he says, every Sanskrit Grammar is constructed; and he has attempted to show "the practical advantages which it offers even for elementary instruction." It will perhaps be a long time before this system comes into general use in teaching the Greek and Latin languages; but there are now many teachers and scholars who know what it is. The study of Latin is a necessity in England, and can never be neglected in a good education. We may hope that it will be taught better than it has been; for the aid which Latin, when it is taught well, gives towards the etymology of our own highly Latinized tongue, is, as Mr. Key says, "a secondary but still an important consideration; and here again the crude forms have a marked advantage over the nominatives." Mr. Key's Latin Grammar is an excellent work, superior in its design to any other, and, as some persons think, in the execution also. Those who are not yet prepared to use the crude-form system in their teaching will find the part on Syntax very useful*.

---

* Mr. Key says in a note:—"In the year 1836 was published the Bromsgrove Latin Grammar, by the Rev. G. A. Jacob (late Scholar and Tutor of Worcester College, Oxford), which is drawn up in a great measure, but far from uniformly, upon the crude-form system. Mr. Jacob subsequently published a Greek Grammar on the same plan."

The Philological Essays of Mr. Key were "in part published for the first time, in part reprinted from the Transactions of the Philological Society, but with many changes or additions." Of the useful essays in this volume, the following, in Two Parts, is worth a careful study:—"Quaeritur. The Sanskrit language as the basis of Linguistic Science; and the labours of the German School in that field, are they not overvalued?" The author acknowledges the deepest obligations of all classical students to the scholars of Germany; and he adds that in the question which he is now considering, the word "overvalued" is "quite compatible with an admission of great value;" and this great value he does not deny. He also acknowledges the signal services of Bopp, the founder, as he is named, of the science of Comparative Grammar. The particular objections to some of the opinions of the Sanskritists can only be learned from the essay. The objections to some of the theories of Bopp appear to be unanswerable; some of those theories are properly termed "extravagancies," and it is hard to conceive that any student of language can accept them.

The second part of "Quaeritur" treats of the 'Vergleichende Grammatik' of Bopp, the first portion of which was published in 1833. The book was republished with some changes and considerable additions in 1857–60. Mr. Key objects to the precedence which Bopp gives "to writing over sound;" or, in other words, to languages which are written over languages which are only spoken; and he objects for this reason, that "the error, so to call it, has told unfavourably on the arguments that follow." Accordingly Mr. Key objects to Bopp's designation of *a*, *i*, *u* as the three original vowels, which error proceeds from Bopp not looking "upon the materials for oral language as belonging to the domain of physical science, and wholly independent of those other forms of language which are addressed to the eye." Bopp's error also proceeds from knowing nothing of Professor Willis's experiments (p. 272) on the vowel-sounds, which sounds "pass by imperceptible gradations from the one extreme *i* (the sound in *feet*) to the other *u* (or *oo* in *boot*)." The varieties of vowel-sounds are therefore infinite, or practically unlimited—a fact which a careful observer of human speech would certainly know. Another objection made to Bopp's work is this:—"The German philologer departing from the course marked out by his Indian authorities, refuses to accept the doctrine that all words are traceable back to verbs." This matter is discussed by Mr. Key at some length.

Mr. Key's last work is on 'Language, its Origin and Development' (1874). By language he means oral language; and he says, "in this sense the word language will be always used, unless the contrary be stated." He adds, "a nobler subject of study cannot be conceived, for it forms the main instrument of man's superior development, to which he owes it that he stands so far above the rest of the animal world." We shall here consider only the theories of the origin of language; but the remainder of the book will well repay the labour of those who will read it carefully.

---

* There is an article by Mr. Key on the advantages of the crude-form system in Bell's 'English Journal of Education' for December 1850, vol. iv. New Series, p. 446.

The theory of James Harris, in his 'Hermes,' is that a "word is a voice articulate and significant by compact." This theory may now be allowed to repose quietly with Rousseau's theory of the Social Contract; no man will disturb their rest. There are two other theories of the origin of Language, one of which is thus stated by Professor Max Müller:—"that man in his primitive and perfect state possessed the faculty of giving expression to the rational conceptions of his mind;" "that this faculty was an instinct, an instinct of the mind as irresistible as any other instinct;" and further, "the faculty peculiar to man in his primitive state, by which every impression from without received its vocal expression from within, must be accepted as an ultimate fact." This theory puts an end to all inquiries on the origin of language. Whether the progenitors of the human race were one perfect pair or many perfect pairs, they could transmit their language to their children in the way in which it is now transmitted. But language is subject to change in the course of time and under new circumstances; and it is easily corrupted, as we know. The conclusion from this theory is that all languages which have existed and exist now, even the imperfect languages of savage people, are derived from this language of man "in his primitive and perfect state."

The other theory is that of Mr. Key, and of others also, that language has been made by man. All men speak, and all have the same organs of speech; but there is a wonderful diversity in their speech; and yet, as they use the same organs, we may expect to find some resemblance in their language, varied, however, by circumstances which are very different and often very difficult to estimate. Mr. Key says, "I conclude with the expression of a strong opinion that original language is mimetic, in other words, consisted solely in the imitation of natural sounds;" and in another place he says that "it is all but universally admitted that some portion of language owes its origin to an imitation of the sounds of nature."

According to this theory man in his primitive state was not perfect, and he could not even speak; his progress towards speaking was like his progress to other useful sciences and arts, slow and laborious through long ages of suffering and sorrow. The ancient writers had a perception of this melancholy truth, as Horace (Sat. i. 3. 99) when he wrote

> "Cum prorepserunt primis animalia terris,
> Mutum et turpe pecus," &c.;

on which Lyell ('Antiquity of Man') says, "The opinion entertained generally by the classical writers of Greece and Rome, that man in the first stage of his existence *was but just removed* from the brutes, is faithfully expressed by Horace. The picture of transmutation given in these verses, however severe and contemptuous the strictures lavishly bestowed on it by Christian commentators, accords singularly with the train of thought which the modern doctrine of progressive development has encouraged." Those Comparative Grammarians, then, who accept this theory may still find something to do; and they may try to explain the slow steps from imitation of natural sounds to the state in which language has existed and exists now among nations named civilized, and also among other nations where it is still near to its supposed original and rude condition. Mr. Key has done something towards this end; but future students of language may and ought to do more.

Mr. Key left an unfinished Latin Dictionary, the work of many years, for the Latin Language was the chief subject on which he was employed as a student and teacher. In the Preface to his work on Language (March 1874) he describes the Dictionary as filling more than 2400 pages of quarto MS., and including nearly all those words in which he thought himself able to make some improvement. In the interval between 1874 and his death he made large additions to the MS., and his friends hope that the work may be published. It will probably contain things which some scholars may not accept; but it will certainly contain much valuable and original matter, such as may be expected from the long labours of an excellent Latin scholar and a student of language generally.

Mr. Key was tall, and his personal appearance was very striking and agreeable, especially when he was animated. His countenance expressed great force of character and penetration. A marble bust of him by T. Woolner, R.A., was presented to University College a few months before his death by some of his old pupils and friends.

The character of Mr. Key may be partially known by those who read what he has written. It was as elevated as his intellectual powers. He was singularly modest and unaffected, but bold and free in his opinions. He was a very good-tempered man, and an agreeable companion, an affectionate husband and father, a teacher beloved by his pupils, a faithful and generous friend, and a man of unspotted integrity. No person knew him so well and so long as the writer of this notice, who for more than half a century enjoyed his friendship without one moment of interruption.

CHARLES WHEATSTONE was born in February 1802, in the vicinity of Gloucester, and was educated at a private school in his native city, at which he evinced his predilection for Mathematics and Physics. In 1823, at the age of 21, we find him, in conjunction with his brother, long since deceased, engaged in the manufacture and sale of musical instruments in London. But his genius was not long in finding opportunities of development; for in the same year he made his first contribution to science in a paper published in Thomson's 'Annals of Philosophy,' entitled "New experiments on Sound," containing the results of his earlier experiments on the vibrations of chords, rods, and surfaces, which excited so much attention among physicists, that it was reproduced the same year in the 'Annales de Chimie,' and in the following year in 'Schweigger's Jahrbuch.' His next papers, also on Acoustics, were published in the 'Quarterly Journal of Science,' on "New experiments on Audition," in 1827, and on "the Kaleidophone," in the following year. This elegant philosophical toy consists of a steel wire fixed vertically in a heavy base, or in a vice, and surmounted by a silvered glass bead. If this, by an appropriate displacement, be thrown into a compound vibration, consisting of the simple vibration of its entire length accompanied by that of the first harmonic subdivision, a series of beautiful circular or elliptic epicycloidal curves are revealed by the persistence on the retina of the reflection of a fixed light from the glass bead; and if a rectangular wire be employed, the dimensions of which are such that its periods of vibration in two planes at right angles to each other are in the simple harmonic ratios of 1 : 2, 2 : 3, or 3 : 4, the curves formed respectively by the superposition of these two modes of vibration will be beautifully exhibited. Subsequently, by an aptly contrived mechanism, Wheatstone succeeded in obtaining a visual combination of rectangular vibrations in any given ratio to each other. The principle of the kaleidophone was subsequently applied in the construction of a photometer. In this instrument a silvered bead is made to describe rapidly a narrow ellipse, or to oscillate in a straight line by means of an epicyclic train of the simplest construction; the relative brightness of two lines, formed by the reflections of two lights to be compared, may be very readily estimated.

At this period of his life Acoustics (doubtless in relation to his business) engrossed the chief part of Wheatstone's attention. He was especially interested in the application of the free reed to musical instruments; and the elegant little Symphonion, which, from the many objections to the needless employment of the breath, soon gave place to the bellows of the Accordion, offered ample evidence of the success of his labours in this direction. In the construction of these instruments, the admirable mode of fingering, in which the successive notes are placed in double rows alternately on opposite sides of the instrument, so that consecutive notes on either side, which may be touched by the same finger, always belong to the same chord, must not remain unnoticed.

In 1828 Wheatstone wrote on the resonance of columns of air, and in 1831 on the transmission of musical sounds through rigid linear conductors, a subject which was subsequently well illustrated at the Polytechnic Institution by the transference to an upper room of music played in the basement. In the same year he contributed to the British Association an experimental proof of Bernouilli's theory of the vibrations of air in wind instruments. His principal contribution to Acoustics is a memoir on the so-called Chladni's figures, produced by strewing sand on elastic planes, and throwing them into vibration by means of a violin-bow drawn across the edge; this was presented to the Royal Society in 1833, and subsequently published in their Transactions, and is probably the most remarkable of his early scientific labours; for he showed that, in square or rectangular plates, every figure however complicated was the resultant of two or more sets of isochronous parallel vibrations; and by means of some simple geometrical relations he carried out the principle of the "superposition of small motions" without the aid of any profound mathematical analysis, and succeeded in predicting the curves that given modes of vibration should produce.

In 1834 Wheatstone was appointed to the chair of Experimental Physics at King's College, London. In fulfilment of the duties of his office he delivered a course of eight lectures on Sound in the early part of the following year; but his habitual though unreasonable distrust of his own powers of utterance proved to be an invincible obstacle, and he soon afterwards discontinued his lectures, but retained the professorship for many years. Although any one would be charmed by his able and lucid exposition of any scientific fact or principle *in private*, yet his attempt to repeat the same process *in public* invariably proved unsatisfactory. An anecdote may here be mentioned in confirmation of this his peculiar idiosyncracy. Wheatstone and the writer of this memoir were for several years members of a small private debating society, comprising several familiar names in science, art, or literature, that met periodically at one another's houses to discuss some extemporized subject, and every member present was expected to speak: Wheatstone could never be induced to open his lips, even on subjects on which he was brimful of information. Several of his more important investigations were for the same reasons from time to time brought before the public by Faraday in the theatre of the Royal Institution.

In 1835 Wheatstone communicated to the British Association a paper "On the Attempts which have been made to imitate Human Speech by Mechanical Means;" and he produced a much improved edition of De Kempelen's speaking-machine; but his researches in this direction were not long continued, and have since been far surpassed by others.

The analogies of vibratory motion led the philosophic mind of Wheatstone from the subject of sound to that of light. In 1838 he communicated to the Royal Society an account of some remarkable and hitherto unobserved phenomena of binocular vision, with a description of the reflecting stereoscope, an instrument by which these phenomena were first illustrated. The conception that the idea of solidity is derived from the mental combination of two pictures of the same object in dissimilar perspective, as seen by the two eyes respectively, is undoubtedly and solely due to Wheatstone. In demonstration of this principle he drew two outlines of the same geometrical figure or other object, just as they would be seen in perspective by either eye respectively; and these outlines were so placed that they might be seen each by one eye, but visually superposed, either by reflection or by refraction; this he effected by a combination of lenses either with plane reflectors or with prisms. All that is really due to Brewster in relation to the stereoscope is the use of wedge-shaped segments of larger lenses, in which the lens and prism of Wheatstone are combined; the construction now universally adopted, and popularized by the application of photography.

In 1852 Wheatstone presented a second memoir on Binocular Vision to the Royal Society, in which he produced a striking confirmation of his former views by the invention of the Pseudoscope, an instrument in which the perspective pictures of a given object as seen by the two eyes respectively are reversed by internal reflection from the bases of two right-angled prisms, and convex objects appear to be concave, or *vice versâ*; thus a globe on which figures are traced will appear to be concave, and the inside of a painted basin or saucer to be convex, or the object as it were turned inside out.

The use of this instrument has produced some curious illustrations of mental phenomena: with most persons an object, of which the convexity or concavity is unknown, will at once appear inverted; but when the real form is known, with some persons experience appears to overrule visual perception, and they cannot succeed in seeing the inversion of the object; with others the appearance derived from previous knowledge persists for a shorter or longer period, and then suddenly gives way to the visual impression, and the object appears to be suddenly turned inside out; while with others, again, the change is more or less gradual, and during the period of transition the visual impression is uncertain and indistinct. In this memoir the idea of the mental character of binocular vision was still further supported by experimental evidence that the *apparent* magnitude of objects is governed by the relative position as well as the size of the visual pictures. In fact the whole of these investigations may be viewed in their relation to mental conditions; and when thus regarded, they possessed a higher interest than that which arose from their great value as contributions to physiological optics.

At one period, indeed, Wheatstone's attention was for a time directed to problems of mental philosophy, and especially to the *quasi*-mechanical solution of some of them, which was hoped for by the followers of Gall and Spurzheim; he was an active member of the London Phrenological Society, then presided over by Dr. Elliotson; and in January 1832 he read at one of the meetings a paper on Dreaming and Somnambulism, which was published *in extenso* in the 'Lancet' of that date. This paper is remarkable, like all his writings, for the extreme clearness with which known facts are stated, and the deductions based upon them.

Amongst Wheatstone's many ingenious inventions may be mentioned his automatic apparatus for recording periodically the height of the barometer, and the temperatures of the dry- and wet-bulb thermometers, by means of wires descending vertically in the open tubes, a circuit closed by the contact of the wire with either column of mercury indicating by electro-magnetic action the moment at which the contact takes place, and by inference the position of the point of contact. Precisely the same principle, with minor modifications, has of late years been practically applied by Padre Secchi, and more recently by M. van Rysselberghe.

Another is the electro-magnetic counter, by which the number of any given repeated mechanical actions is readily and certainly recorded; and the electric chronoscope, by which very small intervals of time may be determined (as, for example, in estimating the velocity of projectiles), must also be mentioned.

Cryptography, or the art of writing in ciphers, is indebted to him for a compendious apparatus, by which the characters representing the successive letters of the written communication are periodically changed by the machine, so as to defy the ordinary well-known methods of deciphering. The receiver, possessing a machine set by agreement in the same manner as that of the sender, can immediately decipher the dispatch by reversing the process by which the cipher was constructed.

The fact, discovered by Brewster, that the plane of polarization of the sky is always 90° from the sun, gave rise to Wheatstone's "Polar Clock," which consists of a double-image prism and a thin plate of selenite enclosed in a tube placed parallel to the earth's axis. When the prism, which carries an index traversing a circular arc marked with the hours, is turned round until no colour is perceived, the index, when once adjusted, will mark the hour of the day; this is a pleasing philosophical toy, but of little practical utility.

The name of Wheatstone is intimately connected with the earliest development of spectrum-analysis. In a paper on "The Prismatic Analysis of Electric Light," read before the Meeting of the British Association at Dublin in 1835, he announced the existence of bright lines in the spectrum, emitted by the incandescent vapour of metals volatilized by the heat of an electric discharge. He was then the first to demonstrate the fact that the spectrum of the electric spark from different metals presented respectively more or less numerous rays of definite refrangibility, producing each a series of lines differing in position and colour from each other, and that thus the presence of a very minute portion of any given metal might be determined. "We have here," he adds, "a mode of discriminating metallic bodies more readily than that of chemical examination, and which may hereafter be employed for useful purposes." This remark has been abundantly verified by the many important recent investigations that have been based on spectrum-analysis—such, for example, as the discovery and isolation of thallium by Mr. Crookes.

It would occupy too much space to enumerate all Wheatstone's ingenious contrivances; but his most important contribution to the wants or conveniences of civilization, the *practical* electric telegraph, must now be considered. On this point it has been justly remarked by De la Rive* that "the philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving to electric telegraphy the practical character that it now possesses, is undoubtedly Mr. Wheatstone." He has no more claim to the title of "inventor" of the electric telegraph than any one of those who have long preceded him in proposing unpractical schemes for transmitting signals to a distant station, first by franklinic, and subsequently by voltaic electricity. The earliest of these appears to be Stephen Gray, who in 1727 suspended by silk threads a wire 700 feet long; and on applying an excited glass tube to one end of the wire electrification was observed by an assistant to occur at the other end. Similar experiments were made by Dufay a few years subsequently, and by Winckler of Leipsic, by Lemonnier of Paris in 1746, and by Dr. Watson, Bishop of Llandaff, in 1747, one of whose experiments had a remarkable (but then unnoticed) bearing on electro-telegraphy, namely, the employment of the earth to conduct the return current: he stretched a wire across the Thames, one end of which was attached to the exterior coating of a Leyden jar, while the interior coating was connected to earth through the body of the experimenter, and the other end was held by an assistant, who grasped an iron rod; the moment the latter dipped the rod in the river both felt a shock. He subsequently experimented on much longer circuits, one of which was 10,600 feet in length, suspended from wooden poles erected on Shooter's Hill. Franklin made similar experiments across the Schuykill at Philadelphia in 1748, and De Luc about the same time across the Lake of Geneva.

The earliest definite scheme for the employment of franklinic electricity for telegraphic purposes was propounded by "C. M.," an anonymous writer in the 'Scot's Magazine' for 1753; this required a separate insulated conductor for each letter; and a very similar idea was subsequently carried out at Geneva by Lesage in 1774. Lomond was the first to propose in 1787 the transmission of various signals through a single line-wire; this he effected by the varied movement of the pith balls of a delicate electroscope; and Cavallo in 1795 proposed to effect the same object by varied combinations of sparks and pauses. In 1816 Francis Ronalds proposed the hopeless scheme of employing two *perfectly isochronous* clocks to indicate continuously the same letters or numerals at the two stations, the signal intended being indicated by simultaneous sparks at both. This telegraph was offered to the Government by the inventor, who received an official reply from the then Secretary of the Admiralty, that "telegraphs of any kind are now wholly useless, and no other than the one now in use will be adopted"—a conspicuous example of the slow progress proverbially due to the inertia of great bodies.

The first proposal to employ voltaic electricity for telegraphic purposes appears to have been made by S. T. Sömmering, a surgeon, to the Academy of Sciences at Munich in 1808; this involved a separate insulated conductor for each letter and numeral, any two of which might be indicated by a small evolution of gas from two corresponding gold points immersed in a common fluid. A very similar system was suggested by Prof. Coxe of Philadelphia in 1810, who proposed to indicate the signals by the decomposition of some metallic salt. Prof. Schweigger of Erlangen proposed to reduce the number of conductors in Sömmering's telegraph to two, and to employ an electric pistol to call attention at the receiving station.

---

* '*Treatise on Electricity,*' pt. vii. ch. 1.

In relation to the dawn of practical electro-telegraphy, the names of Froment in France, of Gauss, Weber, and Steinheil in Germany, and of Morse in America, will immediately suggest themselves, but to Charles Wheatstone is undoubtedly due the merit of having been the first to render the electric telegraph practically available. In 1834, the year of his appointment to the Professorship, he devised an experiment which at once attracted the attention of scientific minds throughout Europe, and ultimately had a large influence in determining the direction of his future labours. His object was to ascertain the rate at which an electric wave travels through a metallic conductor. For this purpose about half a mile of copper wire was insulated by suspension in the vaults under King's College; and three interruptions of this circuit were made by three pairs of small brass knobs, with a small interval between them, placed in a horizontal line at a few inches distance from each other, one being near each end of the conductor, and the other one at its middle point. It was presumable that the positive and negative terminal sparks produced by the discharge of a Leyden jar through the insulated wire would be absolutely simultaneous, but if any perceptible time were occupied by the passage of the wave, the middle spark would occur *later* than the terminal ones. To determine this a small plane mirror mounted on an axis parallel to the line of sparks was made to revolve with great rapidity by a train of clockwork. If any sensible angle were described by the mirror during the passage of the wave, the middle spark would be seen either above or below the line joining the other two, according to the direction of rotation of the mirror. This in fact proved to be the case; and from the estimated amount of displacement and rate of rotation, the velocity of transmission was inferred to be over 250,000 miles in one second; but from the nature of the observation the limits of error are necessarily very wide. This experiment was subsequently repeated with an extended circuit of nearly four miles, which was further utilized in the transmission of electric signals by the deflections of a galvanometer-needle.

In 1836 Mr. W. F. Cooke having been struck, during a visit to Germany, by the applicability of an electric telegraph devised by Baron Schilling to practical and especially to railway purposes, brought back with him on his return to London a working model of Schilling's apparatus, to which he directed the attention of Faraday and of the then Secretary of the Royal Society, Dr. Roget, by whom he was informed that Wheatstone had been for some time engaged in analogous investigations. An introduction followed, and shortly afterwards Wheatstone entered into partnership with Mr. Cooke, and a patent for a five-needle telegraph (which from the number of insulated conductors was deemed too expensive for general use), and subsequently another patent for the two-needle telegraph, the first that came into general use, were taken out in their joint names.

To Mr. (now Sir W. F.) Cooke much credit is undoubtedly due for the tact and ability he evinced in directing public attention to the importance of the electric telegraph, and in conducting the joint enterprise to a most successful commercial issue; but to Wheatstone alone must be ascribed the inventive genius and fertility of scientific resource which led to the many successive developments of the electric telegraph—the letter-showing dial telegraph in 1840, the type-printing telegraph in 1841, the magneto-electric dial telegraph, a subsequent extension of the same to type-embossing, and lastly the automatic telegraph, by which messages are transmitted with such unprecedented rapidity. It must also be borne in mind that the idea of subaqueous telegraphy was first developed by Wheatstone. It appears from his manuscripts that in 1837 he devoted a good deal of time and attention to this subject; and in the Bulletin de l'Académie Royale de Bruxelles for October 7, 1840, in a notice by Prof. Quetelet of his telegraph instruments, it is remarked:—"On sera sans doute charmé d'apprendre que l'auteur a trouvé le moyen de transmettre les signaux entre l'Angleterre et la Belgique, malgré l'obstacle de la mer." But it appears that his first practical essays at submarine telegraphy were made in the autumn of 1844 in Swansea Bay, with the assistance of Mr. J. D. Llewellyn.

More recently the Society of Arts, in tendering precisely the same award for public services to the two former partners, failed to discriminate between very successful commercial tact and ability, and both inventive and constructive genius of an exceptionally high order; under these circumstances it is not surprising that Wheatstone should have declined the proffered distinction, considering that he could present no claim to that commercial merit which it must be, from its title, the special function of that Society to foster. But scientific honours were profusely bestowed on the great physicist; he was elected a Fellow of the Royal Society in 1836, a Chevalier of the Legion of Honour in 1855, and a foreign Associate of the Academy of Sciences of France in 1873; he moreover possessed thirty-four distinctions or diplomas conferred upon him by various governments, universities, and learned societies, of which eight are German, six French, five English, three Swiss, two Scotch, two Italian, two American, and of Irish, Belgian, Russian, Swedish, Dutch, and Brazilian each one. In 1868 the Government of Lord Derby conferred on him the honour of knighthood, an honour so variously bestowed that it can only be viewed as a bare recognition of scientific labours which have rarely been equalled in their extent, their variety, and their fruitfulness.

Charles Wheatstone was not less conspicuous for his sagacity in perceiving the practical bearings of ascertained scientific principles, than for his ingenuity in devising suitable mechanical means for their application to useful purposes. He was one of the first, if not the very first, in this country, to appreciate the importance of Ohm's beautiful and simple law of the relation between electromotive force, resistance of conductors, and resulting current; he thence rightly inferred that in establishing electric intercommunication between two distant stations by means of the deflections of a galvanometer-needle, or the attraction of an iron keeper by an electromagnet, the coil of which is actuated by a current sent from the other station, the resistance of the coil must necessarily be small compared with that of the intervening conductor, and hence that a coil of much larger resistance than was at first contemplated might be beneficially employed: Ohm's law in fact affords the means of determining in any given circuit the quality of coil by which the largest amount of dynamic energy may be imparted to the moving mechanism.

Very early in his electrical researches Wheatstone perceived the necessity of some more accurate means of measuring resistances and the strength of currents than even the most sensitive tangent-galvanometer presented; it occurred to him that small differences between two currents might be much more accurately determined by sending them in *opposite directions* through the coil of a sensitive sine-galvanometer, the needle of which will then be affected only by their *difference*, than by estimating the small differences of displacement of the needle due to small differences in a single current. Accordingly he devised the well-known "Bridge," which has been, and must ever continue to be, the basis of all accurate quantitative determinations in electricity. In this instrument the two portions of a divided current are conducted in opposite directions through the galvanometer-coil and again reunited; and the resistance sought is interposed in one circuit, and "balanced" by known resistance interposed in the other circuit until the needle is brought to zero. The form of this instrument has varied considerably from that originally proposed, but the principle is precisely the same.

As necessary adjuncts to this instrument, Wheatstone proposed as a unit of resistance one foot in length of soft pure copper wire, weighing 100 grains, and constructed a series of "resistance-coils," each coil containing some decimal multiple of the proposed unit; he also devised the "rheostat," consisting of a fine wire wound in the thread of a screw cut on the surface of a cylinder of non-conducting material, any portion of which wire may be put into or taken out of the circuit by merely turning the cylinder on its axis by a handle. But several circumstances rendered

Wheatstone's proposed unit unavailable, viz. the difficulty of maintaining uniformity in the size and quality of the wire, the variation of resistance produced by any molecular disturbance, such as change of temperature, stretching or bending, and the instability of resistance, even when the wire is protected from mechanical disturbance; and the British Association unit is now generally adopted.

Wheatstone was the first to appreciate the importance of reducing to a minimum the amount of work to be done by the current at the receiving station, by diminishing as far as practicable the mass and therefore the inertia of the moving parts; this was beautifully exemplified in that marvel of ingenuity the magneto-electric letter-showing telegraph, now generally adopted for private telegraphic communication, in which the wheel attached to the index is as delicate as the scape-wheel of a small Geneva watch. And there are one or two more points of construction in this admirable instrument which, as exemplars of the mind of the inventor, should not escape notice. Faraday had discovered that if a soft iron keeper furnished with armatures revolve in front of the poles of a permanent magnet, instantaneous currents in opposite directions are developed as the revolving keeper approaches to and recedes from the position of maximum induction; accordingly Wheatstone placed four fixed armatures coiled alternately in opposite directions in front of the poles of a small but powerful permanent magnet, and made the keeper alone to rotate in close proximity to the iron cores of the armatures; as therefore the extra currents induced by the keeper in *receding* from one and *approaching* the other pair of armatures coincide in direction and reinforce each other, four equal currents, alternately positive and negative, will be developed by each revolution of the iron keeper; and these, by causing a pair of magnetic needles, moving on an axis passing through their common centre of gravity, to oscillate between a pair of small electro-magnets, actuate the index of the receiving instrument.

Another peculiarly happy and simple contrivance in this apparatus must also be mentioned. The letters of the alphabet surround the transmitting-dial; and opposite each of these is a stud at the end of a radial lever, the depression of which closes a short circuit, which intercepts all currents when the index arrives at the corresponding letter, and the indicator of the receiving instrument consequently stops at the same letter, it having been first ascertained that they start in unison. It then became necessary that the depression of any other lever should raise the one previously depressed; and for this purpose some very complicated arrangements of interacting levers were first devised, but the plan adopted is remarkable for its simplicity: a circular endless chain lies in a groove beneath all the levers, in which there is just "slack" enough to allow of the depression of *one* lever; consequently the depression of any other pulls up the former, and opens the short circuit previously closed.

The catalogue of Wheatstone's valuable labours is still far from being exhausted; but it must now suffice only to mention some of his unpublished and incomplete researches, of which many exist, and will be, it is hoped, by some means made public. At the early part of his career, when his thoughts were mainly directed to Acoustics, he endeavoured to investigate the causes of the differences of "timbre" or *quality* of tone in different musical instruments, presuming it to depend on the nature of superposed secondary vibrations, and of the material by which they are affected. This the writer has frequently, but in vain, urged him to complete and publish; but such was the fecundity of his imagination that he would frequently work steadily for a time at a given subject, and then entirely put it aside in pursuit, it may be, of some more important or more practical idea that had presented itself to his mind. A short treatise is in existence on the capabilities of his well-known wave-machine, in which rows of white balls, mounted on rods, are actuated in two directions perpendicular to each other by guides or templets with suitable curved outlines; by means of this machine many combinations of plane and helical waves may be demonstrated, and especially those related to the theory of polarized light.

In furtherance of this subject he devised a new form or mode of geometrical analysis, to which he gave the title of Bifarial Algebra, in which both the magnitude and the relative position of lines on a plane surface are designed to be represented by the introduction of two new symbols to represent positive and negative perpendicular directions. The same principle has also been extended to three dimensions, with a further proposal of new symbols, under the name of Trifarial Algebra. On this subject a brief treatise exists in manuscript.

Amongst the subjects of his more recent but still incomplete investigations in Light and Electricity the following may be mentioned:—

Colours of transparent and opaque bodies.
Colours obtained by transmission and reflection.
Absorption-bands in coloured liquids.
Spectroscopic examination of light reflected from opaque and dichroic bodies.
Electromotive forces of various combinations.
Inductive capacities of various bodies.
Experiments on electro-capillarity.
Telegraph construction.
Construction of relays.

Such of these as may be found sufficiently advanced to be of any scientific value will probably be made public in a collective form.

Charles Wheatstone was married on the 12th of February, 1847, and had a family of five children, who survive him, Mrs. Wheatstone having deceased many years. He died in Paris on the 19th of October, 1875, whence his remains were removed to his residence in Park Crescent, and were followed to their last resting-place in the cemetery at Kensal Green by a numerous assemblage of attached friends, with some of whom he had maintained an uninterrupted intimacy from his early manhood, and by several leading members of the scientific world, who felt it due to his great merit to pay this last tribute of regard to his memory.

This memoir cannot be more suitably concluded than by the expressions of M. Dumas, perpetual Secretary of the French Academy of Sciences, uttered on the occasion of the removal of the remains from Paris:—

"To render to genius the homage which is its due, without regard to country or origin, is to honour one's self. The Paris Academy of Sciences, always sympathizing with English science, did not hesitate, during the troubled time of the wars of the Empire, to decree a 'grand prix' to Sir Humphry Davy. Now in a time of peace it comes to fulfil with grief a duty of affection to one of his noblest successors, by gathering round his coffin to offer him a last homage. A foreign Associate of the Academy of Sciences, exercising by a rare privilege in virtue of that title all the rights of its members during his life, we are bound to render to his mortal remains the same tribute which we render to fellow-countrymen who are our colleagues. The memory of Sir C. Wheatstone will live among us not only for his discoveries and for the methods of investigation with which he has endowed science, but also by the recollection of his rare qualities of heart, the uprightness of his character, and the agreeable charm of his personal demeanour. The friends that he has left among us, unable to avert destiny, hope that they were at least able to soothe the last hours of his life—of that life which, alas! was closed away from his beloved home, from that family circle the sweet recollection of which animated his last hours, and to which the eye of the dying one turned once more, before his soul, quitting its earthly tenement, took its flight to a better world."

Justus Liebig was born at Darmstadt on the 13th of May, 1803. He went to school at the Gymnasium of that town. His father was a dealer in drugs and colours. Experiments in the production of colours and chemical products undertaken by his father early excited in the youthful Liebig a fondness for chemistry, which was further developed by the study of the chemical works in the Darmstadt Library. It is stated that in the fourteenth year of his age there was not a volume of a chemical journal in this large library that he had not read through, and that there was no chemical experiment which he had not repeated when his means permitted. The ease with which he obtained all that was requisite for experimenting procured for him early great dexterity in the art of analysis.

His was one of those fortunate natures which early becomes conscious of its power, and he soon made up his mind to be a chemist. His father yielded to his wish to devote himself wholly to chemistry; and Liebig took the only means then available of cultivating the science and placed himself under the tuition of a druggist at Heppenheim. He remained there, however, for only ten months. His taste for analysis found there no scope, and at last an explosion of fulminating silver in the house of his master suddenly terminated his pharmaceutic career. He then returned to Darmstadt, where he passed half a year in further study. At the age of eighteen we find him at the University of Bonn, and he afterwards studied at Erlangen, where he took a degree, and where he published his first chemical paper in 1822.

This paper first appeared in Büchner's 'Repertorium für die Pharmacie,' Band xii., under the title "Ueber die Bereitung und Zusammensetzung des Brugnatellischen und Howard'schen Knallsilbers, von Herrn Liebig, der Chemie Beflissenen aus Darmstadt." Prof. Kastner accompanies this paper with the following notice:—"The readers must receive with indulgence this first attempt of a young chemist. The author has already studied chemistry zealously in Bonn, and has pursued his studies here in Erlangen in the same spirit."

Liebig had felt while at Erlangen the necessity of going to Paris to complete his education; and he was fortunate enough to obtain from the Grand Duke of Darmstadt a travelling stipend for that object. In 1823 we find him in Paris. It was his earnest wish to be admitted to Gay-Lussac's Laboratory; this, however, could not be, as Gay-Lussac at that time admitted no young people. He succeeded, however, in entering Thénard's Laboratory, and there he resumed his investigation of fulminating silver.

This research brought him to the meeting of the French Academy of Sciences in July 1823, which was to form an era in Liebig's life. He read a paper "On an Analytical Examination of Howard's Fulminating Silver and Mercury Compounds." At the conclusion of the meeting, as he was engaged in packing up his preparations, a Member of the Academy came forward and entered into conversation with him. With the most captivating friendliness the stranger made inquiries about Liebig's studies and other occupations and plans, and invited him to dinner at the Palais Royal. They separated without Liebig having had courage to inquire who the stranger was. It was Alexander von Hümboldt, who had returned to Paris the day before from Italy after a long absence. Humboldt now recommended his young countryman, who had so quickly and completely won his heart, to his friend Gay-Lussac, for Humboldt knew too well from his own experience the value of working under Gay-Lussac.

The time which Liebig spent with Gay-Lussac is indisputably the most interesting part of his student life. We may imagine the pleasure these two men must have had in their intercourse: the one 4 years of age and at the summit of his fame, the other scarce 20 years old but full of promise of future greatness. It is related by Liebig that when they had accomplished some difficult work, such, for instance, as satisfactorily finishing a difficult analysis, Gay-Lussac would often take him by the hand and the two would dance together around the laboratory table.

The result of Liebig's study under Gay-Lussac was that the latter recommended the youth so strongly to the Grand Duke Ludwig, that the Grand Duke on his own responsibility appointed him Professor Extraordinary of Chemistry at the University of Giessen. It will easily be understood that Liebig was regarded with jealousy by the majority of his elder colleagues, and found but little support and sympathy in his endeavours for the reform of chemical instruction.

Liebig, however, was able to overcome all obstacles. Two years afterwards he was promoted to the Professorship of Chemistry. He made every arrangement within his power, even at his own personal expense and risk, for his own and his students' work. His reputation rapidly increased; and when it had at last spread to such an extent that young chemists came from all parts of Europe to work under him, the State at length resolved to build him a large Chemical Laboratory outside of Giessen.

Liebig's scientific activity may be divided into two periods, the first from 1824 to about 1839, which was specially devoted to pure Chemistry, and the second from 1840, when his labours in the department of Applied Chemistry began to be prominent.

There is scarcely a branch of chemistry into which Liebig's activity did not extend. Perhaps no other chemist excepting Berzelius had accomplished so many difficult investigations. The 'Annalen der Chemie und Pharmacie,' which he edited conjointly with others, contain more than 200 papers on various branches of pure and applied chemistry.

Great as were Liebig's services in all branches of the science, that of Organic Chemistry is chiefly indebted to him, and he is accordingly called the founder of Organic Chemistry. There may be a difference of opinion as to how far its foundation was already laid, but it cannot be denied that Liebig contributed more than any other chemist of his time to the edifice.

The so-called organic substances originating in plants and animals had, at the period when Liebig entered on his scientific career, been already the subject of many chemical researches, and it was already known that all, unlimited as they are in number, contained carbon combined with hydrogen, and sometimes oxygen or nitrogen in regular proportions; but just as it was supposed that they owed their origin to other than chemical forces, it was imagined that their relation to each other was something quite different from that subsisting between inorganic mineral substances.

But Liebig soon came to the distinct conviction that even if there were a generic difference between organic and inorganic substances, no chemical difference could be assumed. He was convinced that there could be only one chemistry, and took upon himself the task of effecting a scientific connexion between the two branches. His investigation of fulminic acid had already carried him in this direction. He and Gay-Lussac had found it to be a compound of carbon, nitrogen, and oxygen, and he then discovered the corresponding compound of cyanogen with sulphur, and investigated melam and its other products of decomposition.

After Graham had established the tribasic character of the common phosphates, Liebig showed that some organic salts had a similar constitution. But peculiar difficulty was presented by the constitution of certain neutral organic substances, such as alcohol, ether, essential oils, &c. Liebig endeavoured to get a key to their constitution by investigating the action of simple materials upon them, such as chlorine and bromine, &c., and often led his students into this line of work.

In this way a great number of the most remarkable substances were discovered, some of which in future years were of practical use, though the object of the investigator was purely scientific. Thus Liebig discovered chloral long before Liebreich discovered its medicinal qualities.

These labours of Liebig appeared at first to the masses as a useless toying with chemistry, and were often laughed at. To this the very unusual names selected may possibly have contributed: as an instance we may mention the following:—When he found out the composition of a to him most important compound, which he looked upon as alcohol which had parted with some of its hydrogen, he named the new substance Aldehyde, an abbreviation of alcohol dehydrogenisatus. This strangely sounding word excited the astonishment or even the derision of those who had been accustomed to hear new mineral substances named either after the places where they had been discovered or after their inventors, or after distinguished or influential persons, or to hear people speak of Scheele's and Schweinfurt green or Berlin blue.

For Liebig the chief difference between organic and inorganic substances was that the former contain compound radicals, whereas the latter are similarly built up of elements. A joint research of Liebig and Wöhler on the subject of compound radicals was fruitful of important results. They examined oil of bitter almonds and benzoic acid, and discovered the radical benzoyl, a group of three elements, which was capable of combining like an element with chlorine, hydrogen, &c.

Berzelius was greatly interested in this discovery, and declared that it was the dawn of a new day in Vegetable Chemistry. He went so far as to say that he would like to see the first radical discovered, which consisted of more than two simple substances, named Proin or Orthrin.

No man is infallible; and Liebig, of course, made occasional mistakes.

It is said by Dr. Pettenkofer that if he thought a substance was this or that, or contained some particular body, he would frequently ask a student, in whom he had confidence, to examine the substance. If the student failed to find at once what Liebig expected, his confidence in the skill of the student always fell much more quickly than his confidence in the justice of his original idea. He would even naïvely say, "But you must find it." If the student still failed to find it he would sink still lower in Liebig's opinion, but would be sure to raise himself again if he took an independent tone and gave indisputable proofs that Liebig's idea was erroneous, and suggested a better explanation of the phenomena. Of course it was natural that this habit of adherence to an idea once taken up increased on Liebig with years.

But what furthered Liebig's progress so much alongside with his unusual mental gifts and quickness of comprehension was his methodical way of working. He saved himself and others an immense amount of time in research by adopting good methods.

Liebig had learnt elementary analysis with Thénard and Gay-Lussac; but when he set to work with such intensity at Giessen to determine the carbon, hydrogen, and nitrogen of organic bodies, it must have been most annoying to him to require so much time and apparatus. Just as he had in his early years at Erlangen made up his mind that he must go to Paris to complete his education, so he now saw that he must contrive a simpler method of elementary analysis if Organic Chemistry was to be developed. This important task occupied him for some years, but he accomplished it at last. By degrees he got the apparatus into such a simple and sure form that it surpassed in quickness and accuracy the ordinary methods of mineral analysis. This being accomplished, the questions about the quantitative composition of organic bodies could now be easily answered.

The five-bulb apparatus which Liebig contrived to make out of glass tubing enabled him to absorb with facility and accuracy the carbonic acid formed by the combustion of organic bodies. It has become an emblem of the Giessen school. Probably the most important service rendered by Liebig to science was the establishment of the Giessen School of Chemistry. He had experienced in his own person the difficulty of getting a training in the higher branches of the science from the lack of chemical schools. This difficulty had at length been overcome in his case; but only his individual wants were thus satisfied by his accidental meeting with A. von Humboldt, by whose means he was admitted to Gay-Lussac's Laboratory. What he had obtained by a happy accident he made accessible to all in Germany. The founding of the Chemical Laboratory in Giessen, for purposes of public and practical instruction, was quite an epoch in the history of science. What unexampled activity reigned in those Chemical Halls! There met and worked from morning to evening the future professor of chemistry, the future manufacturer. All the dialects of Germany might be heard there, nay every European language, and in one hall, somewhat predominating, the English language—all mixing and yet in order, for every one felt that he was striving for a noble object; he was serving science; in other words, he was a pupil of Liebig. And how inspiriting was this meeting together of earnest youths under such a master! Many a noble and life-long friendship was founded by community of work and aims. And Liebig had mostly a bit of good advice or a happy thought, which helped one who had got into either a scientific or an experimental difficulty, and which would float him again in the right direction.

All who know what this school of Liebig on the Lahn was, and what other opportunities there existed for chemical study, will easily comprehend that there was a time when any one who had a longing for thorough chemical study felt an irresistible call to Giessen. Liebig is much to be applauded and admired in that he knew so clearly the kind of school he must make in order to effect real good. Others before him had felt that chemical students ought to do practical work in the laboratory; but they had not the support of public opinion, or of the governing bodies of educational institutions, and were not strong enough to break through the hindrances around them. It is even told that when one professor at a small University attempted to have a little practical school of Chemistry, his colleagues regarded it as a useless squandering of reagents and coals; and the few students who went to this class were quite pitied by the rest for their credulity in fancying the professor would be so foolish as to show them the right operations and make them professors too.

From the very first Liebig went on the principle of teaching his pupils chemistry without any reference to special applications, and of putting them in possession of the knowledge which they were afterwards to apply. The application he left to themselves. Just then many so-called technical schools were being founded where it was intended that only such parts of natural science should be taught as were useful for some branch of industry. In such a school the future brewer should study malt and hops, the dyer colours, the agriculturist soils and manures, and so on, but not be burdened with subjects of which the pupil in his future career was not likely to make any practical application. Liebig stedfastly opposed this unintelligent utilitarianism.

People in great technical businesses soon began to see how perfectly in the right Liebig was in this idea; and he was constantly applied to, not merely for chemical teachers, but even for chemists, and not merely for chemists to assist in chemical works and soda manufactories, but for paper manufactories, colour works, breweries, &c.

In this way not merely eminent investigators and teachers came forth from Liebig's school, but many very distinguished practical men. Two other subjects yet remain to be mentioned to complete the picture of

Liebig's scientific activity—'The Annals of Chemistry and Pharmacy' and his 'Letters on Chemistry.'

Before Liebig's time there was no periodical which was exclusively devoted to Chemistry. Chemistry was then more nearly connected with pharmacy; and as in the practice of pharmacy the results of chemistry came so closely into application, Liebig's first researches were published in the Magazine for Pharmacy founded by the apothecary Hänle, and afterwards continued by the apothecary Geiger in Heidelberg.

In the year 1832 Liebig founded, in conjunction with Geiger, the 'Annalen der Pharmacie,' which now became entirely his organ. With the publication of the 33rd volume, Wöhler became one of the editors, and the title was changed to 'Annalen der Chemie und Pharmacie,' in order, as Liebig said, to bring the title and the contents more into unison. Later on Kopp, and still later Erlenmeyer and Volhard, all pupils of Liebig, joined in the editing.

The 'Chemical Letters,' as is well known, originated in a series of essays published in the Augsburg Gazette. These letters were remarkable specimens of exact science popularized for educated people.

Liebig's active mind led him to an earnest consideration of the chemical processes involved in agriculture and physiology. Having paid more attention to the study of organic bodies than any other chemist, he naturally felt a desire to consider these substances in connexion with their functions, and the circumstances under which they were developed. How fruitful his labours were in this direction is already well known.

What is called Liebig's agricultural chemistry was developed in two periods. The first period from 1840 to 1846 in Giessen, and the second from 1856 to 1862 in Munich, whither he migrated in 1852. His views on vegetable and animal physiology were first expounded in a work which was published by Vieweg in Brunswick in 1840, with the title "Die Chemie in ihrer Anwendung auf Agricultur und Physiologie."

This book originated in the following manner:—The British Association for the Advancement of Science, at its Liverpool Meeting in 1837, requested Liebig to publish a report of the present state of knowledge in the department of Organic Chemistry. He expressed his willingness to do so, but proposed that Dumas should share the task with him. Dumas seemed disinclined, and Liebig brought out his 'Agricultural Chemistry.' The result of its publication was astonishing. It went through no less than six important editions in six consecutive years, and excited an immense amount of interest. The stir made by this book was so great that Dumas, as the first chemical authority in France, felt it necessary one year later to publish a somewhat similar work in the French language, and formally to claim for France on this occasion the main principles enunciated in Liebig's work: "Elles appartiennent à notre école dont l'esprit est venu s'exercer sur ce terrain nouveau."

Many of Liebig's countrymen expressed strong dissent from his views;

and Berzelius at first expressed himself as very doubtful about them,' and after some years got into actual hostility with Liebig about this application of chemistry, which he called "Probabilitäts-Theorien." In his Jahresbericht of 1841, Berzelius said that Liebig's book was executed with all the talent which one would expect of so distinguished an author, but he does not conceal his opinion that Liebig had erected an edifice which was but too insecure. He said that Boussingault was working in the same field as Liebig, but was taking the long and difficult road, answering every inquiry by one or more experiments, that he did not give his answers so quickly, but they might be relied on.

This partly cautious, partly dissentient, and partly actually hostile attitude of the agriculturists, physiologists, and chemists seemed only to tune to a louder key the enthusiasm and applause of the general public; but this was probably no satisfaction to Liebig, for of all the applauding crowd who besides his own pupils surrounded him, not one was able to bring Berzelius over to different views, to weaken the experiments of Braconnot, and the objections of Boussingault, or to convince the sceptical agriculturists and controversial physiologists.

Then, perhaps for the first time in his life, Liebig may have oft felt right lonely, despite the homage of the masses; for even his best friends and scholars saw too well that Liebig in this high flight (this book) had often maintained more than he had proved, that the proof was in many points still wanting.

At no time did Liebig profess to be the first who had made chemical experiments in agriculture. In fact, in the dedication of his book to Alexander von Humboldt, he says, "I hardly know whether even a part of the little work which I make bold to dedicate to you is my own."

What, then, was it which caused so much excitement? It was the idea which Liebig brought so prominently forward, that plants alone are capable of assimilating inorganic materials, such as carbonic acid, water, and ammonia, and of building up complex substances such as albumen, starch, and fat, &c.; while animals live upon these complex products and reduce them to simpler ones.

Liebig undertook the determination of the ashes in several parts of many varieties of plants and from different localities. He cared little for analyses of soils hitherto considered so important, especially how much humus an earth contained, but he wanted specially to know what each plant did with the earth on which it grew.

It soon appeared that all plants leave qualitatively the same mineral constituents in their ashes, but that every kind of plant, so to say, yields its own peculiar ash, inasmuch as different kinds, even when growing on the same soil, take up its mineral constituents in very different proportions. It was soon found that wheat, rye, barley, &c. have their distinct ashes, also the grains of a corn compared to the corresponding straws.

As it was not enough to know the ashes of a particular plant grown in a particular region, but was desirable to get them from as many different plants, fields, and regions as possible, so Liebig procured ashes from all possible localities. Just as a merchant writes letters of business to all parts, so Liebig sent about letters everywhere for analyses of ashes.

In order to make the work of analysis as easy as possible, his pupils Will and Fresenius had worked out and published an excellent method of ash analysis; and in a short time thousands of analyses were made of the most different plants and parts of plants in very different localities. He found that each plant takes an exact quantity of mineral matter and in an exact proportion, which may be recovered again from its ashes; and he concluded that whatever else the plant requires for the formation of its combustible constituents is derived from the carbonic acid, water, and ammonia of the air. From these views Liebig laid down the rule that to keep a wheat or corn-field fertile one has only to return to it the mineral constituents which have been taken out by the crops, and in the proportions in which those minerals are present in the ashes of each crop.

Liebig induced the distinguished alkali manufacturer Muspratt, in Liverpool, to prepare mineral manures for wheat, rye, oats, clover, potato, and other fields. The different manures were manufactured according to a method invented by Liebig, which consisted in melting together the necessary substances, so that salts easily soluble in water were brought into an almost insoluble form that the rain might not carry them off out of reach of the germinating seed. Liebig was as much convinced of the soundness of his mineral theories as of the working power of his mineral manure. But matters turned out differently from what he anticipated, and a heavy trial was in store for his great genius.

The English agriculturists saw no result from his artificial manure, ceased to buy it, and again had recourse to dung and other substances, and the factory in Liverpool ceased to work. Nay, even Liebig was himself convinced by his unsuccessful experiments in agriculture in Giessen that his mineral manure could not make a barren soil more fertile. One single ray of hope came to cheer him after years of failure. It turned out that after a length of time those fields when no longer manured at length became more fertile. But here again was a new riddle for him.

Meanwhile adversaries rose up, not merely to expose the uselessness of his manure, but also to show that new methods must be adopted in order to reach a practical end.

In the foreground stood an English agriculturist, Lawes, who soon joined with an excellent chemist, Gilbert, and made on one of his estates experiments with all sorts of manures, which they manufactured and tried in many different ways. It was shown that the more soluble a substance is, the more effect it has; that the yield of a field is often increased merely by the addition of bone-ash rendered soluble by sulphuric acid (so-called superphosphate); but that above all ammonia and ammoniacal salts, or, as they at last boldly stated it, combined nitrogen must be added to the fields in order to secure good crops; and for a while the value of a manure was simply estimated by the amount of nitrogen it contained, whereas Liebig's theory had pointed out the atmosphere as a sufficient source of supply of ammonia.

Liebig's adversaries were at this time banded together under the appellation of Nitrogenists (*Stickstöffler*). They thought they had driven Liebig for ever from the field.

In spite of all Liebig remained true to his theory and would not yield. He controverted the conclusions of Lawes and Gilbert, but without success. The President of the English Agricultural Society, Pusey, ranged himself distinctly on the side of Lawes and Gilbert. As the masses only judge by results, the sale of the book 'Chemie in ihrer Anwendung auf Agricultur und Physiologie,' which at first could not be printed fast enough, became smaller and smaller, and after 1846 no new edition appeared.

In his latest writings on the subject of the mineral theory Liebig acknowledged that ammonia may with advantage be supplied to cereal and some other crops in the manure; but contended at the same time that it was naturally included among "mineral substances" which he had originally referred to. As, however, he had clearly explained that the ashes of a plant contain the mineral substances which ought to be added to the soil for the growth of such plant, the statement that ammonia is really a mineral compound, and ought to be included in his rule regarding mineral substances, really conceded in substance the argument of his opponents.

Since the year 1845 Liebig had paid more and more attention to the second part of the task which he had set himself in 1840, the application of chemistry to animal physiology, and was in full work at this when King Maximilian II. entered into a correspondence with him with the view of calling him to Munich. Liebig had in the course of his distinguished career declined so many calls (shortly before this one a brilliant call to Heidelberg), that they had little hope of persuading the eminent man to come to Munich, but they induced him nevertheless. To his honour be it said he did not in the least render the task more difficult by great pretensions, merely stipulating that he should not be required to conduct so large a laboratory as he had done at Giessen, so that he might have more time for his own work. His migration took place in the autumn of 1852, when in his 49th year.

After some time he resumed at Munich his agricultural experiments, and at last found out why his mineral manure had not the desired effect, and why dung and even mere ammoniacal salts alone had so great an effect.

In the year 1862 appeared his great work, in two volumes, 'Der chemische Process der Ernährung der Vegetabilien und die Naturgesetze des Feldbaues.' This was the crowning work of Liebig's agricultural labours, and his doctrine is now universally recognized; and no thoughtful agriculturist ever now supposes that he need but add superphosphate or nitrogen or guano and his fields will be for ever fertile. It is now in agriculture but a question of the best appliances necessary to do justice to the theory of Liebig. In Germany agriculturists have thankfully acknowledged this by the foundation of the Liebig Stiftung.

In close connexion with the subject of nutrition is Liebig's work on flesh, which first gave us a more exact idea of the chemical composition of muscle, that is by far the greatest and most massive part of our bodily organs. One result of this work is the Liebig's Meat Extract, now well known to the whole world, of which so much has been said, and whose value has been as often over- as underrated.

Liebig spent the remainder of his life at Munich, where he died on the 10th of April, 1873.

Auguste Arthur de la Rive, born at Geneva on the 9th of October, 1801, was the son of Charles Gaspard de la Rive, Professor of Chemistry and Physics in the Academy of Geneva. He studied first at the College and then at the Academy. After working at science for a time he devoted himself to the study of law for two or three years. He had inherited his father's taste for science. In the year 1822 he became deeply interested in Ampère's investigations; and when Ampère's theory of the magnet had lost its best support, the young Auguste de la Rive came to his assistance. He performed a series of delicate experiments, which Ampère came expressly to Présinge, the country place of the De la Rives, to witness. The memoir "On the Influence of Terrestrial Magnetism upon a movable frame traversed by a Voltaic Current," written by the young physicist on this occasion, contains not only the new results which he had obtained, but the learned and conclusive theory by which Ampère connects them with his own views, thenceforth completely triumphant. This first research not only brought him into connexion with Ampère, but paved the way for his long and intimate friendship with Faraday.

In October 1823 he gave up his legal studies and succeeded M. Prevost as Professor of Physique Générale at the Academy. On the occasion of his candidateship he published a thesis, "Dissertation sur la partie de l'optique qui traite des courbes dites caustiques." He had also to give some lessons at the Academy and a public conference on the theory of the pendulum. On the death of M. A. Pictet in 1825 he resigned the chair of Physique Générale to succeed to that of Experimental Physics. He often gave, in addition to his regular lessons, some special course on Electro-chemistry, or courses for a general audience, conjointly with M. Marcet, besides others for the industrial classes.

Auguste de la Rive contributed evidence in favour of the general conclusion that it is as impossible to create force as to create matter. He also gave much attention to the cause of the Aurora Borealis, taking up the subject where Arago had left it; and by means of an apparatus arranged by himself he was able to show the chief peculiarities of this phenomenon. By the passage of electricity through a rarefied gas he caused the appearance of a luminous ring animated with a rotatory movement round this same pole. This experiment is so remarkable that it will always be admired even by those physicists who, considering the aurora to have its source higher up than the terrestrial atmosphere, attribute to it a cosmical origin, which De la Rive would never admit.

Shortly before he was attacked by the malady which finally killed him, he wrote to Dumas, "Aidez-moi à défendre une théorie fondée sur des faits incontestables; elle était déjà celle de Franklin et d'Arago, avec moins de précision. Les auteurs qui ne songent qu'aux aurores brillantes oublient que presque tous les jours il y en a qui se passent sans éclat, dans les régions polaires; je ne connais pas un seul observateur placé dans nos contrées septentrionales qui n'ait adopté les vues que j'ai exposées. N'est-ce pas une présomption en leur faveur que d'avoir pour elles tous ceux qui vivent au milieu des phénomènes qu'elles cherchent à expliquer? Faudrait-il les abandonner, quand on a seulement contre elles ceux qui ne les observent que de loin en loin, sous l'impression aveuglante d'une surprise qui ne laisse pas toujours une entière liberté d'appréciation?"

In connexion with this subject we may mention that Auguste de la Rive and his friend M. de Marignac made experiments to show that ozone is modified oxygen, oxygen which has undergone a change by the action of electricity.

The investigations of Auguste de la Rive gave rise to a new and now flourishing branch of industry, Galvanic Gilding. Hitherto the only effectual method known of gilding bronze was by the use of mercury; but the process was most injurious to the workmen, as their hands came in contact with the dangerous metal, and their chests were exposed to the action of mercury vapour during the heating operation. A prize had been offered by the French Academy to any one who could find a method which should remove the dangers from this trade; but nobody had hitherto solved the problem. The Academy has since been more fortunate. The process of galvanic gilding has been developed; and we must not forget that the learned and disinterested physicist Auguste de la Rive with his own hands gilded the first pieces by the electric process. He it was who showed how to put an end to the distressing bodily and mental sufferings of these workmen. For this discovery, published in 1840, he received the Prix Monthyon of 3000 francs from the French Academy.

A. de la Rive made numerous observations on the causes of the second reflections seen at sunset on Mont Blanc, and attributed them to the last rays of the sun falling on some layers of vapour collected in the upper regions of the atmosphere. He showed that these vapours, themselves characteristic of fine weather, are formed by actual particles of dust &c., whether mineral or organic, suspended in the air, where they float when dry, falling to the ground when made heavy by moisture. When abundant they cause a haziness of the atmosphere, when in small quantity the clearness of the atmosphere returns.

Even the insects fluttering about obey this law. If swallows skim the ground at the approach of rain and reascend in fine weather, it is because in the first case the insects charged with damp cannot rise, and in the second case are relieved from this weight and mount high up in the air.

A. de la Rive took a deep interest in political questions. He was always liberal in his views, but at the same time determined to resist extreme democracy.

After the revolution of Geneva, at the period of the war of the Sonderbund, he resigned his professorship and gave up public life. He was, however, on the occasion of the annexation of Savoy to France, appointed to watch over the interests of the Helvetic Confederation in London. He was received with great distinction by the Queen, and on his return made one of the Assembly elected to revise the constitution of Geneva. After this work was accomplished he retired entirely from public affairs.

In the spring of 1873 he was attacked with paralysis, but was, nevertheless, able to read in a feeble voice on June 5th his annual report to the Société de Physique et d'Histoire Naturelle. In the November following he had a severe stroke of paralysis on his way to Cannes, but managed to reach Marseilles, where he died on the 27th.

His wife only survived him a few days.

De la Rive's principal work was the 'Traité d'Électricité Théorique et Appliquée,' in three volumes, which appeared between the years 1854 and 1858, in which he published his theory of the Aurora Borealis, first brought forward in 1854, and illustrated by the experiment now well known to physicists of rotating the voltaic arc of light around the pole of a magnet, as any other ponderable conductor would rotate. This work was published simultaneously in France and England.

During a period of fifty years he made many contributions to Science, which were published in the 'Mémoires de la Société de Physique et d'Histoire Universelle de Genève' or in the 'Bibliothèque Universelle.' From 1836 to 1845 he edited the literary and scientific parts of the 'Bibliothèque Universelle,' which were then united. He compiled alone, as supplementary to it, the 'Archives de l'Électricité,' in five volumes, 1841 to 1845, and conjointly with De Marignac and others the 'Archives des Sciences Physiques et Naturelles,' in thirty-six volumes, 1846 to 1857, and the 'Nouvelle Période' of the same Recueil, in nine volumes, 1858 to 1860. He was also the author of numerous biographies and of papers on optics, critical and scientific notices. He took an active part in the Society for the Advancement of the Arts, and was for several years General President of the Society. He twice presided, in 1845 and in 1865, over the Helvetic Society of Natural Sciences. With the Prix Monthyon, received from the Académie des Sciences for electro-chemical gilding, he founded a quinquennial prize to be given to the author of the discovery most useful to Genevese industry, and he augmented this sum by a legacy. He was a foreign member of the French Academy and of the Royal Society.

PROCEEDINGS

OF

THE ROYAL SOCIETY.

THE BAKERIAN LECTURE.—"On the Forms of Equipotential Curves and Surfaces and on Lines of Flow." By W. G. ADAMS, M.A., F.R.S., Professor of Natural Philosophy and Astronomy in King's College, London. Received February 18, 1875*.

[PLATES 1 & 2.]

When any portion of a conducting-wire which joins the two poles of a voltaic battery is increased in size, the resistance of the circuit is diminished and a greater current flows through the wire; and as any increase in the cross section of any portion of the wire causes a corresponding increase in the current, it is clear that there is no part of the conducting-wire through which some portion of the current does not flow from the one pole to the other; and the outer boundary of such a wire will be a line of flow.

A line of flow is a line drawn in a conductor which indicates at every point of it the direction of the current at that point. A portion of the conductor completely enclosed by lines of flow may be termed a tube of flow.

If a portion of the wire be beaten out into a flat disk, or if a sheet of metal or tinfoil be employed, it will still be true that there is no part of it to which the lines of flow do not extend, although the amount of current will be weak at points of the disk which are far removed from the shortest line of flow.

If instead of a variable wire or disk the circuit consist in part of a conducting liquid whose cross section is greater than the surface of the electrodes in the liquid, the lines of flow extend throughout the liquid; and an increase in the cross section of the liquid diminishes to some extent the resistance of the circuit.

---

* *Read February 25, 1875.* See vol. xxiii. p. 280.

The lines of flow diverge from the electrodes or points where the current enters and leaves the liquid, and lie closer and closer together as they lie nearer to the shortest line of flow joining the electrodes.

The whole of the conductor, whether it be a disk or a liquid, may be regarded as being made up of tubes of flow, or of bundles of lines of flow, each tube ending in conical points filling up the same solid angle at the electrodes, and conveying a given quantity of electricity from one battery-electrode to the other.

These tubes increase in diameter at points further and further from the electrodes; and the strength of current at a given point (*i. e.* the quantity of current flowing through a perpendicular section of unit area) will be inversely as the cross section of the tube of flow passing through that point. In passing from one electrode to the other along any line of flow there will be a gradual fall of potential, and the lines of flow will be cut at right angles by surfaces in which the potential is the same for every point of the same surface.

On attaching two wires to a galvanometer, and placing their free ends on the same equipotential surface, no current will flow through the galvanometer.

If, then, two electrodes in connexion with the two poles of a battery be fixed in contact with two points of a disk of tinfoil, or with two points in a conducting liquid, and two other electrodes be attached to a delicate galvanometer, by keeping one of these fixed and tracing with the other we may determine the forms of equipotential curves or surfaces in the disk of tinfoil or in the liquid by joining all the positions of the tracing-pole which give no current through the galvanometer.

It will be convenient to call the electrodes which are connected with the battery the battery-electrodes, and those connected with the galvanometer the galvanometer-electrodes. By means of the tracing-electrode points of the same potential as the fixed galvanometer-electrode may be marked on the tinfoil; and the curve joining them will be an equipotential curve.

Experimental Work.

About five years ago, at the suggestion of Mr. J. T. Bottomley, the tracing out of equipotential curves on sheets of tinfoil was first set as an exercise for our more advanced students in the Physical Laboratory. I have been assisted in the experimental work contained in this paper by Messrs. Jacob, Cochrane, Day, and Harrison, students in the Physical Laboratory of King's College.

To trace the curves, one electrode of a Thomson's reflecting galvanometer was attached to a small screw or pin, fixed in contact with or passing through the tinfoil disk; and the other galvanometer-electrode was attached to a small tube of the same size as the screw, with the end of which contact could be made at any point of the disk. In the centre of this small tube a needle was held by a spring; and when the required point was found, by pressing down the spring a hole could be made in the tinfoil, thus marking the position of the tracing-electrode.

The best form of contact is probably by means of needle-points, on which shoulders of metal 2 or 3 millims. in diameter are soldered, and which are pressed tight on the tinfoil. By placing a sheet of paper underneath the tinfoil disk the forms of equipotential curves are at once pricked out, and may afterwards be drawn. For illustration in lectures the sheet of tinfoil may be placed in front of a lamp, and the forms of equipotential curves or lines of flow may be thrown on a screen. If the curves be traced on a circular disk of the size of or smaller than the condensing-lens, the whole series of equipotential curves on it may be thrown upon the screen at the same time.

Case 1. Plate 1. fig. 1 represents a sheet of tinfoil 310 millims. square, in which A and B, the battery-poles, are 126 millims. apart; and the line AB is nearly parallel to a side, and passes through the centre O of the square; the point O is equidistant from the two poles.

Not far from the centre of the sheet, and in the smaller curves through an angle varying from 60° to 90° about the electrodes, these curves coincide with circles; and in other parts of the curves, when the influence of the edge is taken into account, by supposing the distribution due to charges in the positions of the electric images, as will be afterwards explained, the agreement with the curves as given by theory is remarkably exact.

If a large sheet of tinfoil be taken, and the battery-electrodes be placed far away from the edge of the sheet, then at all points not near the edge of the sheet the forms of the equipotential curves will be very nearly the same as in a sheet of infinite extent.

In all such cases (as will be afterwards shown) the equipotential curves, when there are only two battery-electrodes in connexion with the sheet, are circles having their centres on the straight line passing through the two electrodes; and the lines of flow are also arcs of circles which pass through the two poles.

Case 2. Plate 2. fig. 2 represents a circular sheet of tinfoil, 210 millims. in diameter, with the electrodes on the circumference, and at a distance from one another equal to the radius. The electrodes were small binding-screws placed as closely as possible to the edge of the disk. The differences of potential between two successive equipotential curves have been measured by the deflections of the needle of the galvanometer.

The deflections were as follows:—

From *k* to *a*	150
„ *a* to *b*	50
„ *b* to *c*	50
„ *c* to *e*	50
„ *e to f*	50

From *f* to *g* 50
„ *g* to *h* 80

It will be seen that the fall of potential from *k* to *d* is greater than the fall of potential from *d* to *h*. This may arise from a difference in the resistances of the contacts with the two battery-electrodes.

The radii of the circles are 28, 56, 290, 82, 28, and 12 millims., beginning from the point *k*; and the distances between them, measured along the line joining the electrodes, are 20, 13, 15, 19, 15, 10, and 12 millims.

The distances 13, 15, 19, 15, 10 correspond to equal differences of potential; and hence the resistances of the portions of the disk between these consecutive equipotential curves are equal to one another. In this case there was considerable resistance between the binding-screw and the tinfoil disk at the point of contact; but this does not alter the forms of the equipotential curves.

Case 3. Plate 2. fig. 3 represents a large sheet of tinfoil 18 inches square, with one electrode in the centre, by which the current enters the sheet, and four similar electrodes at four corners of a square, each being 3 inches from the central electrode, by which the currents leave the sheet. The electrodes were needles, with shoulders of brass 3 millims. in diameter soldered on them. The four negative electrodes may be united together beneath the board on which the tinfoil is placed, by strips of copper screwed to the electrodes by a small nut on each needle. On the needles which pass through the tinfoil are shoulders which come down tight on the tinfoil so as to make good contact. For these curves two cells of Grove were used; and the difference of potential between two successive curves causes a deflection of 50 divisions of the scale. The resistances of the portions of this disk between successive equipotential curves are equal to one another.

Case 4. The curves in Plate 2. fig. 4, lying within the octant BAH, are equipotential curves, when one positive electrode A is at the corner of a square sheet of tinfoil of which AH and AM are the edges, and one negative electrode at B, at a distance of 3 inches from A, the line AB bisecting the angle between the two edges. The curves between the lines AB and AM have not been drawn in the figure.

The potential at any point in this sheet is that due to the electrodes, together with the three images of each formed by the rectangular edges; and hence the curves should be the same as in the previous case. On comparing the curves it will be seen that that is the case.

The curves, with two exceptions, are drawn at distances corresponding to equal differences of potential; so that, omitting the interpolated curves, the resistances of the portions of the sheet between two consecutive equipotential curves are equal to one another.

This figure also represents the equipotential curves for a square sheet BAB_1, of which AB and AB_1 are the edges, with one positive electrode at A, and two negative electrodes at B and B_1 on the edges of the sheet.

We may also regard the case with one positive electrode at the centre and four negative electrodes at the corners of a square as equivalent to two sets, each set consisting of one positive and two negative electrodes, one on each side of it, at equal distances along the same straight line on a sheet either unlimited or limited by that straight line.

Case 5. The curves for this arrangement of electrodes are drawn in Plate 1. fig. 5; the distance from the positive to each negative electrode is 76 millims., or 3 inches, as in Cases 3 and 4, the electrodes being near the centre of a very large sheet of tinfoil.

Taking the curve which cuts the axis at a distance of 54 millims. from the centre, and at distances of 1 millim. on either side, the distances r_1, r_1' from the negative electrodes to the several points on the curve differ by the quantities in the following Table.

Values of (r_1-r_1').

For 53 millims.	For 53·75 millims.	For 54 millims.	For 55 millims.
106	108	109	110
105	109	109	110
104	108	110	110
104	108	109	110½
104	108	112	110
101	108	114	111
99			
97			

The curve drawn between those at 53 and 54 millimetres was drawn as nearly as possible at a distance of 53¾ millims. from the centre.

The result of this case shows that in the case of one and four electrodes (Plate 2. fig. 3) we may expect the curves which cut the axis at a distance of about 54 millims. from the centre to be hyperbolas. The fifth curve from the centre is in the position of the rectangular hyperbola, having its foci in the positions of the negative electrodes; and we find, on measuring this curve as well as the curve on the outside of it, that near the vertex the curves are accurately hyperbolas. This is also true of the corresponding curves in fig. 4. The curves first drawn in fig. 5 were drawn at equal distances of 10 millims. apart along the axis, reckoning from the centre; and the differences of potential for these curves, reckoned from the centre, are proportional to the numbers

138, 85, 88, 100, 80,

138 including the effect due to contact of the electrode. Other curves were afterwards interpolated in the neighbourhood of the position of the rectangular hyperbola and around the negative electrodes.

The sheet of tinfoil in the last three cases was sufficiently large for the curves in the neighbourhood of the axis to be similar to those which could have been traced on a sheet of infinite extent.

The third equipotential curve from the negative pole C is the rectangular hyperbola, and its vertex O divides the distance AC; so that

$$\text{AO is to AB as 1 to } \sqrt{2}.$$

AO is equal to 53·75 millimetres.

Case 6. Plate 2. fig. 6 represents the case of a circular disk where the current enters at the edge and leaves at the centre of the disk.

Around the centre the curves are very nearly ellipses of small eccentricity, the focus being at the centre of the disk. If a is the radius of the disk and r the distance from the centre, the eccentricity is $\frac{2r}{a}$.

The curve cutting the axis at the point L at a distance of 16 millims., *i. e.* $(3-2\sqrt{2})\,a$ from the centre, has two branches cutting one another at right angles at the point Q, and each cutting the edge of the disk at an angle of 45°, the radius of the disk being 3·75 inches.

When the fixed galvanometer-electrode is at L, it is difficult to find a succession of points forming a continuous equipotential curve; the tracing-electrode may at one time be placed on the boundary of the shaded portion of the figure, and at another may be placed on the axis near the point Q, without causing any current through the galvanometer.

On placing the fixed galvanometer-electrode at Q, the tracing-electrode marks out two straight lines in the neighbourhood of that point of the same potential as the point Q, and each cutting the edge of the disk at an angle of 45° at that point.

The uncertainty in tracing this equipotential curve is explained, as will be presently shown (p. 25), by the fact that each of the galvanometer-electrodes was rather more than 1 millimetre in diameter.

The equipotential curves which lie further from the centre cut the edge of the disk at right angles.

To determine experimentally the Lines of Flow and the Equipotential Surfaces in Space of three dimensions.

If two platinum wires sealed in glass tubes, with only a short piece of wire projecting from the sealed end, be immersed in a liquid, the other ends being connected with the poles of a battery, we shall have a close approximation to the case of currents flowing from one point to another within a liquid; and by means of two other platinum wires similarly arranged but attached to a galvanometer, we may trace out the forms of equipotential surfaces within the liquid.

If dilute sulphuric acid be employed there will be polarization on the electrodes; but by reversing the current alternately, and making contact only for a short time, the polarization may be kept small on the galvanometer-electrodes, provided they are not moved far away from the same equipotential surface.

After a few preliminary experiments to determine how far the method was practicable, I began a definite series of experiments in March 1872. For the experiments in dilute sulphuric acid, in sulphate of copper, and in sulphate of zinc, I have employed a rectangular wooden box, 1 foot long, 8 inches broad, and 8 inches deep. On the edges of the box are fastened paper millimetre-scales; a piece is cut out of the middle of the ends of the box, and a sliding piece fitted in to carry the battery-electrodes. These sliding pieces are capable of motion parallel to the sides of the box, so as to place the battery-electrodes at different distances from one another (see Plate 1. fig. 8). The galvanometer-electrodes were placed firmly in brass tubes, which were accurately placed on T pieces of wood so as to be in a line with the point of intersection of two edges of the T piece, and to be vertical when the T pieces are placed on the edges of the box. By this means the rectangular coordinates of the point could at once be read off on the sides and ends of the box.

The first experiments were made with the points at a depth of 10 centims. below the surface, the box being nearly full of liquid.

In making the experiments the current was reversed, and the readings of the galvanometer taken on both sides of zero for each position of the electrodes.

The battery employed was 20 Leclanche cells, the resistance of each cell being nearly 3 ohms, and the electromotive force about 1½ of Daniell's cell. The strength of the battery-current was measured by a tangent-galvanometer, of the form of Helmholtz's double galvanometer; the deflection of the needles during these first experiments was generally 46°. The galvanometer-electrodes could be brought up to within 1 centim. of the centre of the box.

The object of the first experiments was to determine the changes of potential for equal changes of distance in a direction parallel to the sides of the box.

The battery-electrodes were placed at 2 millims. distance from the end of the box, *i.e.* at a distance of 300 millims. from one another. The line joining them was one axis of coordinates, the other axis being the upper edge of one end of the box. One of the galvanometer-electrodes was placed at the point (150, 50), and the other was first placed at (30, 50), and moved 1 centim. at a time in a direction parallel to the sides of the box. The deflections were taken at each point, and are recorded in the following Table:—

Coordinates of tracing-electrode.	Mean deflection.	Diff.
50, 30	76	
50, 40	66	10
50, 50	61	5
50, 60	55	6
50, 70	50	5
50, 80	44	6
50, 90	36	8
50, 100	30	6
50, 110	24	6
50, 120	18	6
50, 130	13·5	4·5
50, 140	7	6·5
50, 150	2·5	4·5

Coordinates of tracing-electrode.	Mean deflection.	Diff.
50, 150	2·5	
50, 160	− 6	8·5
50, 170	−11·5	5·5
50, 180	−16	4·5
50, 190	−22	6
50, 200	−28	6
50, 210	−34	6
50, 220	−40	6
50, 230	−47	7
50, 240	−52	5
50, 250	−60	8
50, 260	−68	8
50, 270	−74	6
50, 30	74	
50, 50	60	
50, 150	2	

The column of differences gives the differences of potential between the equipotential surfaces passing through the successive positions of the tracing-electrode. These positions are points at equal distances of 10 millims. apart, along a horizontal straight line parallel to the sides of the box at a distance of 50 millims. from the axis.

The difference between the mean and each of the two deflections to right and left may be taken to be the current due to polarization. This was very small, the deflections being 6 at the beginning, 6·5 at the middle, and 10 at the end of the experiments.

Toward the end of the experiments, at (250, 50) there was an increase of 2 in the deflections because the current was kept on for five minutes. From these results it appears that with momentary currents and reversing at each observation, the variation in the polarization current, even in dilute sulphuric acid, may be kept very small. The sudden change in the polarization at (50, 250) reduced the deflection of the tangent-galvanometer from 46° to 41°.

The value of the deflection recorded is the mean of two or more deflections in each direction, but these were very generally the same.

To reduce, if possible, the effect of polarization, I employed sulphate of copper and gutta-percha-covered copper wire 3·6 millims in diameter, with 4 millims. projecting beyond the covering for the battery-electrodes. In the galvanometer-electrodes, which were of the same covered wire, there were 2 millims. of wire projecting beyond the covering; all the electrodes were immersed to a depth of 75 millims. The battery-electrodes were placed at distances of 10 millims. from the ends of the box, so that they were 284 millims. apart.

The fixed galvanometer-electrode was placed at (152, 50); then on varying the position of the other electrode, it is found that for all positions in a plane parallel to the ends of the box, and dividing it into two equal parts, there is no deflection; but at (151, 50), *i.e.* at a distance of 1 millim. from this plane, there is a deflection of 10 divisions of the scale. Hence the plane which is equidistant from the electrodes is shown to be an equipotential surface. This is the surface at which the potential is zero.

Case 7. Plate 2. fig. 9 represents three sections of three equipotential surfaces, one through the point (50, 10), another through the point (80, 10), and a third through the point (100, 10), the battery-electrodes being placed at distances of 10 millims. from the ends of the box and 284 millims. apart.

When the battery-electrodes are so near to the ends of the box, the distribution of the electric currents, and therefore the forms of the equipotential surfaces, will not be the same as in a conductor which is unlimited in every direction; hence in comparing these experimental results with theory it is necessary to take into account the influence of the ends and sides of the box.

If we measure the distances from each point of a curve to the battery-electrodes and to the positions of their electric images due to the sides and ends of the box, and if for each point we subtract the sum of the reciprocals of the distances of the negative electrode and its images from the sum of the reciprocals of the distances of the positive electrode and its images, we get a series of numbers which differ very little from one another.

If r, r', r'' .... represent the distances from the positive electrode and its images, and r_1, r_1', r_1'' .... represent the distances from the negative electrode and its images, then $\Sigma\left(\frac{1}{r}-\frac{1}{r_1}\right)$ is very nearly constant for each curve.

In Plate 2. fig. 9 the negative electrode is so far away from every point of the curve, that all except one of the electrical images at the distant end of the box have been neglected.

In the case of the curve passing through the point (50, 10), the values of $\Sigma\left(\frac{1}{r}-\frac{1}{r_1}\right)$ for the several points are given in the following table:—

·0444
·0443
·0439
·0435
·0432
·0433

The curves are drawn only on one side of the axis; but they are symmetrical about the axis, and also, with regard to the plane of zero, potential.

Treating the next curve in the same way, the coordinates of the first point taken in this curve are 80, 10, and the battery-electrodes are at the same point as before, $\Sigma\left(\frac{1}{r}-\frac{1}{r_1}\right)$ for each point.

·0316
·0314
·0314
·0312
·0311
·0310
·0311
·0309
·0311
·0311
·0313
·0312
·0315
·0316
·0319

The mean value of $\Sigma\left(\frac{1}{r}-\frac{1}{r_1}\right)=$ ·0313, neglecting all the images but one of the more distant electrode.

These images would diminish the potential at each point, but by very nearly the same amount, as they are so far away from every point of the curve.

Another curve is drawn on this Plate through the point (100, 10). These three curves were drawn with the battery-poles in the same positions.

Case 8. In a curve (see Plate 2. fig. 10) drawn through the point (120, 20), with the electrodes at a distance of 80 millims. from the ends of the box, only the nearest electrical image was taken into account: the values of $\left(\frac{1}{r}-\frac{1}{r_1}+\frac{1}{r'}\right)$ for the several points are:—

·0183
·0181
·0183
·0182
·0183
·0182
·0183
·0183
·0183
0182
·0182
·0178
·0177
·0172
·0173
·0170
·0166
·0167
·0163
·0160

In this case all the images except one are neglected. When the curve approaches near the side of the box, as at these latter points, it becomes necessary to take account of the effect due to the side of the box; and the forms of the curves are completely altered.

Case 9. In the experiments with sulphate of zinc (Plate 1. fig. 11), the zinc electrodes were not immersed to any considerable depth in the liquid, as in the other experiments already described, but were rounded off and immersed to a depth of about 3 or 4 millims., in order to make good contact, the galvanometer-electrodes being somewhat smaller than the others and only just dipping into the liquid. The other arrangements were the same as before. No electrical images were taken into account, as the battery-electrodes were at a distance of 102 millims. from the ends of the box. Taking the first curve described, the values of $\left(\frac{1}{r}-\frac{1}{r_1}\right)$ for the several points are:—

·0139	·0143	·0142
·0136	·0143	·0143
·0137	·0145	·0142
·0141	·0146	·0141
·0143	·0143	·0138

The highest numbers are the values for points which are nearest to the side of the box. The battery-electrodes are 100 millims. apart, and equally distant from the centre of the box. The curve is drawn through the point (180, 15).

Plate 1. fig. 11 also contains another curve for sulphate of zinc, where the electrodes only just dip into the liquid, the battery-electrodes, as before, being 100 millims. apart and equidistant from the centre of the box. The curve is drawn through the point (170, 15). Taking the 40 points which have been determined experimentally for this curve, the values of $\left(\frac{1}{r}-\frac{1}{r_1}\right)$ are contained in the following table, arranged in four columns:—

·0080	·0082	·0083	·0079
·0080	·0081	·0083	·0078
·0078	·0081	·0082	·0078
·0078	·0081	·0080	·0078
·0079	·0081	·0081	·0076
·0079	·0081	·0081	·0077
·0079	·0081	·0080	·0076
·0080	·0081	·0079	·0076
·0081	·0082	·0079	·0074
·0082	·0083	·0079	·0074

The last points taken on the curve are nearer to the side and also to the end of the box than to the nearest electrode; hence for these points corrections should be applied depending on the changes of potential due to the side and end of the box.

It also appears very clearly from this series of values that, by reversing the battery-current at each observation, the polarization of the galvanometer-electrodes may be kept small and very nearly constant throughout a long series of experiments.

Experiments with Linear Electrodes.

Case 10. The rectangular box was also employed to determine the forms of the cylindrical equipotential surfaces when the electrodes are straight rods and extend throughout the depth of the liquid. Sulphate of zinc was employed for these experiments, and the electrodes were amalgamated zinc rods. Plate 2. fig. 12 represents the sections of the equipotential surfaces when one battery-electrode is at A, the centre of the box, and the other at B, the *middle point of one side.*

These electrodes are 100 millims. apart. The galvanometer-electrodes in these experiments could not be brought within less than 5 millims. of the axis of the curves.

The curves drawn represent the sections of equipotential cylindrical surfaces which are at distances of 10 millims. apart, measured along a line which is parallel to and 5 millims. distant from the axis.

The case of a circular cylinder containing sulphate of copper, with the battery-electrodes at the two ends of a diameter, has also been worked out experimentally; and the equipotential surfaces are circular cylinders cutting the sides of the vessel at right angles. Mercury was tried for these experiments; but from its almost perfect conducting-power it was very difficult to determine two vertical lines in it which were precisely of the same potential.

Case 11. Another case was worked out experimentally with line-electrodes in sulphate of zinc. One positive electrode was placed at the middle point of one side of the rectangular box, and two negative electrodes were placed symmetrically at the same distance from the positive electrode; so that the lines joining the positive to the two negative electrodes were at right angles to one another. This corresponds to the case drawn in Plate 2. fig. 4; and the sections of the surfaces at points which are not near the side of the box are the same as the curves in figs. 3 or 4 of Plate 2. Having previously determined the forms of these curves in the tinfoil experiments, it was very easy to move the tracing-electrode from one point to another on the same equipotential curve, by making use of the curves previously drawn as guides for the electrode.

Comparison of Experimental results with the Theory of Electrical Distribution.

To examine the forms of the equipotential curves and surfaces with a view to determine how far the results of experiment agree with and are accounted for by the theory of distribution of electricity in a plane and in space of three dimensions, take first the case of a plane of unlimited extent in every direction, when two battery-electrodes are joined to two points in the plane, so that there are equal and opposite currents at those points. The potential at any point P of the plane is equal to $C-A(\log r-\log r_1)$, where r, r_1 are the distances of the point P from the two battery-electrodes A and B. Hence the condition for an equipotential curve is $\log r-\log r_1=\log c$, or $r=cr_1$, where c is some constant. This equation indicates that the bisector of the angle at any point P between the lines r and r_1 cuts the line joining the two battery-electrodes in the same point, which is a point on the equipotential curve.

If $2a$ is the distance between the electrodes, the distances from A and B to this intermediate point are $\frac{2ac}{1+c}$ and $\frac{2a}{1+c}$. The locus of the point P is a circle whose diameter is $\frac{4ac}{1-c^2}$, and whose centre is on AB produced.

If we refer this circle to rectangular coordinates with the axis of y equidistant from A and B, then its equation is

$$(x-a)^2+y^2=c^2\{(x+a)^2+y^2\},$$

or

$$\left(x-a\,.\,\frac{1+c^2}{1-c^2}\right)^2+y^2=\left(\frac{2ac}{1-c^2}\right)^2.$$

If

$$y=0,\ x=a\,.\,\frac{1+c}{1-c}\ \text{or}\ a\,.\,\frac{1-c}{1+c},$$

giving the points where any equipotential curve cuts the axis.

The point B is the electrical image of A with regard to each of these circles; for if O be the centre of one of the circles,

$$\text{OA}\,.\,\text{OB}=\left(\frac{2ac}{1-c^2}\right)^2.$$

The lines of flow cut the equipotential curves at right angles, or the radius of one of these circles is the tangent to a line of flow; hence it follows (Euclid, Book III. Prop. 8) that the lines of flow are arcs of circles passing through the points A and B, the positions of the electrodes. This result may be arrived at by a method which is also applicable to the case of unequal charges at several points in a plane.

Let us take the equation to the equipotential curves in the form $(x-a)^2+y^2=c^2\{(x+a)^2+y^2\}$. Differentiating and eliminating c we get

$$\frac{(x-a)+y\dfrac{dy}{dx}}{(x-a)^2+y^2}=\frac{(x+a)+y\dfrac{dy}{dx}}{(x+a)^2+y^2}.$$

The lines of flow cut the equipotential curves at right angles; hence for a line of flow

$$\frac{(x-a)\dfrac{dy}{dx}-y}{(x-a)^2+y^2}=\frac{(x+a)\dfrac{dy}{dx}-y}{(x+a)^2+y^2}.$$

Integrating this equation, we get

$$\tan^{-1}\frac{y}{x-a}-\tan^{-1}\frac{y}{x+a}=\text{constant},$$

showing that the lines of flow are circles passing through the positions of the two electrodes. Comparing this result with the curves drawn by experiment in Plate 1. fig. 1, we see that for all parts of the disk which may be considered to be beyond the influence of the edge of the disk, there is a very close agreement between theory and experiment; and the influence of the edge of the disk will be such that the equipotential curves will cut the edge of the disk at right angles.

When the conducting-sheet is not of infinite extent, but of very considerable extent in every direction, the expression $C-A(\log r-\log r_1)$ will still be a close approximation to the potential at any point, provided the electrodes are not *far from the centre* of the sheet. Hence on such a sheet under these conditions the portions of equipotential curves and lines of flow which are not near the edges of the sheet will be very nearly circular. This we have seen to be the case in the experiments on tinfoil (see Plate 1. fig. 1).

When the lines approach near the edge of the disk, or when the electrodes are near the edge, then the form of the equipotential curve is generally altered, because the edge of the disk will generally cut some of the lines of flow of the infinite plane. We may conceive of the lines of flow as distinct from one another, but as filling up the whole of the disk; if, then, we make a section of the disk along a line of flow we do not alter the distribution of electricity on the disk, and so do not alter the forms of the equipotential curves. But in that case, since the two parts of the disk are entirely separate from one another, one of the parts may be taken away without causing any change in the law of distribution of the electric currents in the other.

If, then, we cut away from an indefinite sheet a portion which is bounded by lines of flow, we shall not alter the form of the equipotential curves; but, since we thereby increase the resistance of each portion, we shall increase the difference of potential between the two electrodes, and the distances between successive equipotential curves corresponding to given differences of potential will be diminished.

The straight line joining the battery-electrodes is a line of flow; hence when the electrodes are on one edge of a sheet which is unlimited in all directions but one, the equipotential curves are still arcs of circles having their centres on the straight edge of the disk; or if a portion of the disk bounded by this edge and by the arc of a circle which passes through the two electrodes be cut out, the forms of the equipotential curves in this portion will be arcs of circles with their centres on the straight edge.

The same will apply to any portion bounded by the arcs of two circles passing through the two electrodes; so that on a circular disk with the two electrodes on the circumference, the circular boundary of the disk will be two lines of flow, and the equipotential curves which cut them at right angles will also be circles with their centres on the straight line passing through the two electrodes*. One of the electrodes will be the electrical image of the other with regard to these circles. This has also been proved to be the case by the experiments (see Plate 2. fig. 2).

---

* [*July* 23.—This case has been worked out experimentally by M. Kirchhoff by joining the galvanometer-wires to two points of the plane sheet which are at different potential, and balancing the current which would flow through those wires, by introducing a thermoelectric pile into the galvanometer-circuit. M. Verdet says: "M. Kirchhoff n'a étudié par l'expérience que le cas d'une plaque circulaire communiquant par deux points de sa circonférence avec les réophores d'une pile." M. Kirchhoff used a copper disk, and from its being a good conductor was unable to determine its resistance. M. Verdet also adds that M. Quincke worked out the case of a square disk with one battery-pole at a corner and the other on a diagonal of the square. These two are the only cases con-

If in an infinite plane there be any number of electrodes, the equipotential curves and lines of flow may be drawn by the method explained by Professor Maxwell *, by drawing circles of equal differences of potential around each charge, and joining their point of intersection in such a way that for all the points taken the sum of the potentials is constant.

The potential at any point of the plane is $C+A\log r+B\log r'-E\log r_1-F\log r_1'+\&c.$, where r, r', r_1, r_1' are the distances of the point from the several electrodes.

In the case where the currents are equal at the several points the potential is $C+A\log\left(\frac{r\;r'\;r''\;\ldots}{r_1\;r_1'\;r_1''\;\ldots}\right)$. Hence for an equipotential curve we must have

$$r\,r'\,r''\ldots=c\,r_1\,r_1'\,r_1''\ldots,$$

or $\log r+\log r'+\log r''-\log r_1-\log r_1'-\log r_1''=\log c$.

By differentiating and finding the curves which cut these at right angles we shall find, as on p. 13, that the equation to a line of flow is of the form

$$\Sigma\left\{\tan^{-1}\left(\frac{y-b}{x-a}\right)-\tan^{-1}\left(\frac{y-b_1}{x-a_1}\right)\right\}=\text{constant},$$

or $$\Sigma\,(\theta-\theta_1)=\text{constant}.$$

When currents flow into and out of a plane conducting-sheet at several points of it, the potential at any point of the sheet is

$$C+A\log r+B\log r'-E\log r_1-F\log r_1'+\&c.,$$

where A, B, &c. are proportional to the quantity of current flowing into the sheet, and E, F, &c. to the quantity flowing out at the several battery-electrodes. In the case of battery-electrodes where there is no loss of current from the conducting-sheet, these currents may always be divided up into a series of pairs of equal and opposite currents, so that there will be an equal number of positive and negative terms. If, then,

---

tained in this paper which have been previously worked out experimentally. The case worked out by M. Quincke is shown to be the same as that (Plate 2. fig. 3) of one positive electrode at the centre and four negative electrodes at the four corners of a square in the centre of a sheet of tinfoil which is so large compared with the size of the square, that it may be considered of unlimited extent. Some other cases of limited sheets, with other arrangements of electrodes so as to give the same curves, have also been considered in this paper. Since this paper was read before the Royal Society, Prof. G. C. Foster has given, in the 'Philosophical Magazine' for May and June 1875, an account of the work which had been previously done on this subject, in which he draws attention to an interesting paper on the theory of lines of flow in a plane, by Prof. W. R. Smith, published in the Proceedings of the Royal Society of Edinburgh for 1869–70.]

* *Treatise on Electricity and Magnetism*, vol. i. p. 148.

currents at the several electrodes are all equal, then for an equipotential curve we shall have

$$r\, r'\, r'' \ldots = c\, r_1\, r_1'\, r_1'' \ldots$$

If the current enters at one point and leaves by four currents equal to one another, then

$$r^1 = c\, r_1\, r_1'\, r_1''\, r_1'''.$$

We have an instance of this case (Plate 2. fig. 3) when a current enters a very large sheet of tinfoil at the centre, and leaves by the four corners of a square round this electrode as a centre.

When a current enters a conducting-sheet by one point and leaves in equal currents by two others, the equation to an equipotential curve becomes

$$r^2 = c\, r_1\, r_1',$$

where r is the distance from the positive electrode, and r_1, r_1' the distances from the negative electrodes to any point of the curve.

In the particular case when $c=1$, and when the electrodes are all in the same straight line, this becomes a rectangular hyperbola, the foci of which are the positions of the negative electrodes, and the positive electrode is at the centre of the hyperbola.

This is the case which is given in fig. 5, as worked out experimentally, where the focal distance of the hyperbola is 76 millims., and its vertex is at a distance from the centre equal to 53·75 millims., *i. e.* very nearly $\frac{1}{\sqrt{2}} \times 76$ millims. The measured values of $r_1 - r_1'$, starting from the axis for six successive points some millims. apart from one another, are 108, 109, 108, 108, 108, 108 millims. The theoretical value for this difference is 107·5 millims.

The Theory of Electrical Images.

When there are four equal electrodes with currents entering the sheet by two of them and leaving by the other two, we have

$$rr' = c\, r_1\, r_1'.$$

Consider the case when these four electrodes lie on the circumference of a circle. Join each pair of like electrodes by straight lines, and produce the chords of the circle so joined to meet one another.

Let AA_1, BB_1 be these chords meeting in C. Then the potential at the point C is

$$c + A\{\log(CA\,.\,CA_1) - \log(CB\,.\,CB_1)\} = c.$$

Fig. 1.

Draw round C as centre the circle which cuts the circumference of AA_1B_1B at right angles, and let it cut the circle in H and K, and the chords in E and E_1.

$$\text{Then } CA \,.\, CA_1 = CE^2 = CK^2,$$
$$\text{and } CB \,.\, CB_1 = CE^2_1 = CH^2.$$

If the value of the constant c is zero in the above expression, then the centre C is a point of zero potential.

If we produce the other two chords of the circle to meet in the point O, and take a point D in AB, such that $OA \,.\, OB = OD^2$, and draw a circle about O with OD as radius, then this circle is an equipotential curve for the four electrodes A, A_1, B, B_1. For if P be any point of this circle, then

$$PB : PA :: DB : DA,$$

and

$$PB_1 : PA_1 :: D_1B_1 : D_1A_1 :: DB_1 : DA_1.$$

But the potential at any point, P, due to the four electrodes is

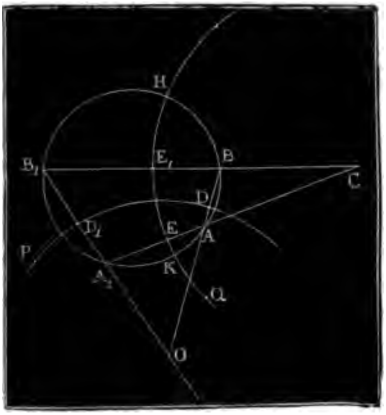
$$A \log \left(\frac{PA \,.\, PA_1}{PB \,.\, PB_1}\right);$$

hence on the circle DD_1 this becomes

$$A \log \left(\frac{DA \,.\, DA_1}{DB \,.\, DB_1}\right),$$

which is the same as the potential at the point D.

Fig. 2.



Since

$$DA : DB :: OD : OB,$$

and

$$D_1A_1 : D_1B_1 :: OA_1 : OD_1, \text{ or } :: OD_1 : OB_1,$$

the potential at D is

$$A \log \left(\frac{OA_1}{OB}\right), \text{ or } A \log \left(\frac{OA}{OB_1}\right), \text{ or } A \log \left(\frac{OD^2}{OB \,.\, OB_1}\right).$$

These results show that the *circle through* DD_1 is an equipotential curve for the four equal electrodes A, A_1, B, B_1; also that the potential at any point of this circle is the same as the potential at the centre O would be if there were only a positive electrode at A and a negative electrode at B_1, which is the same as one half the potential at the centre, O, due to the four electrodes.

If we take two of these electrodes, B, B_1, and through C draw another chord through two other electrodes on the circle, and draw the equipotential circle for this set of four electrodes, we shall find that all such circles cut both the circles AA_1B and EE_1 mutually at right angles, and that the circle EE_1 is a line of flow for all such systems of four electrodes on the circle AA_1, B_1B.

The circles DD_1, EE_1, and AA_1B will intersect mutually at right angles.

This will appear if it is shown that AA_1 and BB_1 intersect on the common chord of the circles DD_1 and AA_1B; for in that case the tangent to DD_1 drawn from C is equal to the radius of EE_1.

Let the circle AA_1B be referred to two tangents through the point C and their common chord ($\gamma=0$); then its equation is $\alpha\beta-\gamma^2=0$.

Let $\mu^2\alpha-\beta=0$ and $\lambda^2\alpha-\beta=0$ be the equations to the two lines CAA_1 and CBB_1.

We may call the points A, A_1, B, B_1, the points μ, $-\mu$, λ, $-\lambda$. The equation to the chord joining μ and λ is

$$\lambda\mu\alpha-(\lambda+\mu)\,\gamma+\beta=0,$$

and the equation to the chord joining $-\mu$ and $-\lambda$ is

$$\lambda\mu\alpha+(\lambda+\mu)\,\gamma+\beta=0.$$

These intersect on the line $\gamma=0$ where it meets $\lambda\mu\alpha+\beta=0$.

The equations to the tangents through this point are

$$\lambda\mu\alpha-2\sqrt{\lambda\mu}\,.\,\gamma+\beta=0$$

and

$$\lambda\mu\alpha+2\sqrt{\lambda\mu}\,.\,\gamma+\beta=0,$$

which touch the circles at the points $\sqrt{\lambda\mu}$ and $-\sqrt{\lambda\mu}$.

The equation to the chord joining these points is

$$\lambda\mu\alpha-\beta=0,$$

which passes through the point (α, β).

The circle HEK is a line of flow for any such system of four equal electrodes as A, A_1, B, B_1, lying on a circle which cuts the circle HEK at right angles.

A particular case of this arises when two of the electrodes of the same kind as A and A_1 approach to and ultimately coincide with K; then the current at K is double each of the currents at B and B_1. The two lines of flow, HEK and KBB_1, intersect at right angles at the point K, and the equipotential circle DD_1 diminishes to a point.

Since the circle HEK is a line of flow, we may cut the conducting sheet along the arc of this circle without changing the form of the equipotential curves. If, then, at two points A and B, on a circular disk HEK, we have two equal and opposite battery-electrodes, the equipotential curves will be the same as the equipotential curves in an infinite sheet which are due to those two electrodes, together with equal and like electrodes at their electrical images with regard to the circle*.

Extension of the Theory of Electrical Images.

We have seen that when the boundary-line of a disk is made up of arcs of circles passing through the two battery-electrodes, then the forms of the lines of flow will be the same as in an infinite sheet; and consequently the forms of the equipotential curves are arcs of circles.

We have also seen that when the boundary of the disk is a circle, and the two electrodes lie within it, the forms of the lines of flow will be altered because of the presence of the edge of the disk; and the change in the electrical distribution will be that due to equal quantities of electricity in the position of the electrical images of the electrodes formed by the edges of the disk. If from a circular disk with two equal battery-electrodes lying within it, we cut off a portion bounded by the arc of that

---

* [*July* 23.—That the circle HEK is a line of flow for the four electrodes may be readily seen if we resolve the rate of flow at any point, Q, of the circumference of this circle in the direction of the radius at that point. As shown by Prof. W. R. Smith, the rate of flow arising from each electrode is inversely as the distance from the electrode.

Let CA$=a_1$, CA$_1=a_1$, AQ$=r$, A$_1$Q$=r'$, and ρ the radius; then, according to Prof. Smith's notation, the resolved part along the radius from the two like electrodes A and A$_1$ will be

$$\frac{E}{2\pi r}\times\frac{r^2+\rho^2-a^2}{2r\rho}+\frac{E}{2\pi r'}\times\frac{r'^2+\rho^2-a_1^2}{2r'\rho},$$

or

$$\frac{E}{2\pi\rho}+\frac{E}{4\pi\rho}\left\{\frac{\rho^2-a^2}{r^2}+\frac{\rho^2-a_1^2}{r'^2}\right\};$$

but

$$\frac{r}{r'}=\frac{\rho-a}{a_1-\rho}=\frac{\rho+a}{a_1+\rho},$$

so that

$$\frac{r^2}{r'^2}=\frac{\rho^2-a^2}{a_1^2-\rho^2};\text{ therefore }\frac{\rho^2-a^2}{r^2}+\frac{\rho^2-a_1^2}{r'^2}=0.$$

Hence the rate of flow along the radius, viz. $\frac{E}{2\pi\rho}$, is the same as if there were an equal electrode at C.

In the same way it may be shown that the rate of flow along the radius arising from the other two electrodes is the same in quantity, but in the opposite direction.

Hence there is no flow along the radius at the point Q when there are two equal positive electrodes at A and A$_1$, and two other equal negative electrodes at B and B$_1$.

So that at every point, Q, of the circle HEK the circumference of the circle must be the *line of flow.*]

circle which passes through the two electrodes and cuts the circular disk at right angles, we shall not alter the forms of the equipotential curves within either of the separate disks bounded by the arcs of these two circles.

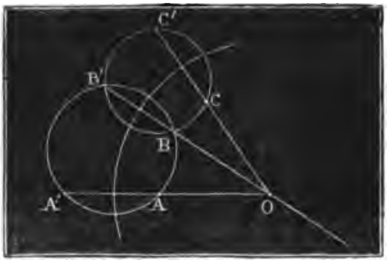
In all these cases the boundary-line will be made up of lines of flow, and the equipotential curves will *generally* cut the edge of the disk at right angles. Or if, in an unlimited sheet, each of two battery-electrodes be divided into two, so that equal currents flow through each point, and if these four electrodes be so arranged that they all lie on the circumference of a circle, then the forms of the equipotential curves will be the same as in the case of a circular disk which has its centre at the point of intersection of the chords joining the two positive electrodes and the two negative electrodes respectively, and whose radius is equal to the tangent drawn from this point to the circle on which the electrodes lie. In the case of the circular disk, the positive electrode outside the disk becomes the virtual electric image of the other positive electrode, and the outside negative electrode becomes the electric image of the other negative electrode. The edge of the disk cuts the other circle at right angles, and is a line of flow for the four equal electrodes in the unlimited sheet. Hence no alteration is made in the forms of the lines of flow by cutting the sheet along this edge.

This will apply to the case of any two unlike equal electrodes within a circular disk when there are any number of electrodes connected with the disk; for if we take all these electrodes and their electric images, and suppose them to be kept continually charged, each image like its point, then in the unlimited sheet the line in the position of the edge of the disk will be a line of flow for every set of two unlike electrodes and their images, and therefore for all of them when taken together.

Hence, by cutting along the edge of the circular disk to which such images are due, no change is made in the lines of flow or in the equipotential curves. In fig. 3, A and C are like electrodes.

When the currents entering or leaving the disk at the several electrodes are not all equal, since the sum of the currents entering the disk must be equal to those leaving it, they may all be divided up into sets of two unlike equal currents; and hence for all cases of currents entering

Fig. 3.



and leaving a circular disk, the edge is in the position of a line of flow for all the electrodes and their images in the unlimited sheet. At an electrode and its image the currents are equal, and must be supposed to be both entering or both leaving the sheet.

In the case when the two equal sets of two unlike electrodes in the unlimited sheet lie at the corners of a rectangle, then the straight lines joining the like poles are bisected at right angles by a straight line, which is a line of flow.

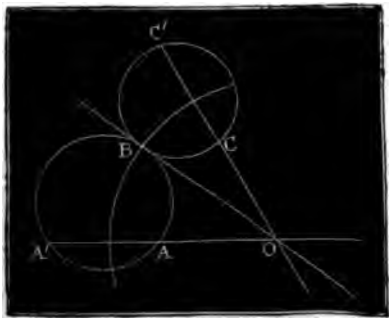
Hence, if the sheet be cut along this straight line, no alteration is made in the lines of flow on either side of it; and the pair of unlike electrodes on one side of it become the images of the electrodes on the other side.

In the case of a plane sheet limited by two lines at right angles, three electrical images of each electrode will be formed by the two rectangular intersecting sides; and these images will be arranged in a circle about the point of intersection, in the same positions as the optical images formed by two plane mirrors at right angles to one another.

The equipotential curves in this case will be the same as those in an infinite sheet when there are four equal electrodes of each kind—the four positive electrodes taking the positions of the one positive electrode and its three images, and the four negative electrodes being similarly placed.

A particular and an interesting case arises when one of the electrodes is on the edge of the circular disk; the electric image of this electrode then coincides with the electrode itself; and the case in an unlimited sheet which corresponds to this is that where a current enters the sheet at one point, and leaves it by equal currents at two other points, the three points lying on a circle which touches the radius of the disk, *i. e.* cuts the disk at right angles, at the point where the current enters the sheet.

Fig. 4.

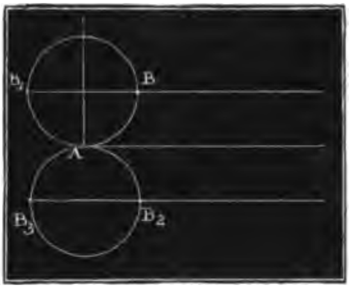


When a current enters a circular disk at one point on the edge, and leaves it by equal currents at two other points, the corresponding case in an unlimited sheet is that where a current enters the sheet at one point and *leaves by equal currents at four other* points lying two and two on circles which touch one another at the point where the current enters the sheet (fig. 4).

If, in an indefinite sheet (Plate 2. fig. 3), one of the battery-electrodes be separated into four parts and attached to the tinfoil at the four corners of a square, and if the other battery-electrode be attached at the centre of the square, then the current at the centre will be four times the current at each corner of the square; and the forms of the equipotential curves will be the same as when there are only two, unlike equal electrodes in a sheet limited in two directions by straight lines meeting at the centre and parallel to the sides of the square, the three electrical images in the limited sheet being in the same positions as three of the electrodes in the unlimited sheet.

This is a particular case of the last, when an electrode and its image lie at the ends of a diameter of the circle, and are equally distant from the point at which the current enters the sheet (fig. 5).

Fig. 5.



The case with one positive electrode at the centre and four negative electrodes at the corners of a square in an unlimited sheet may also be regarded as equivalent to two sets of electrodes, each set consisting of one positive electrode at the corner of a square and two negative electrodes at equal distances along the two edges measured from that corner when the sheet is cut along these two edges.

The curves are also the same as in a sheet limited by two edges at right angles to one another, when one electrode is at the corner and the other on the diagonal of the square sheet, the electrodes being at the same distance as in the two previous cases.

The curves in Plate 2. fig. 4 are drawn on such a sheet with one positive electrode at A and a negative electrode at B, at a distance of 3 inches from A, the whole sheet of tinfoil being 18 inches square.

It may also be regarded as a particular case of two sets of electrodes in an unlimited sheet, where there are three electrodes in each set at equal distances along the same straight line, the current entering at the middle one and flowing out at the other two electrodes. Since the circle is not a line of flow for such a system of electrodes, we cannot have this system of equipotential curves and lines of flow in a circular disk.

A particular solution of this case, the equipotential curve for zero potential, is a rectangular hyperbola, having its centre and two foci at the three electrodes (see Plate 1. fig. 5).

In the case of a circular disk the electric image of the centre may be regarded as a point at an infinite distance, so that the distance of the image from any point of the circular disk remains constant.

If, then, one electrode be at the centre and the other at the circumference of a circular disk (Plate 1. fig. 6), the corresponding case in the unlimited sheet is that where the current flowing in at the circumference is double the current flowing out at the centre, we may conceive of it as a case where there is one electrode at an infinite distance, equal to and of like kind with the electrode at the centre.

In such a case the potential at any point is expressed by $C + A \log r - 2A \log r_1$

Hence for an equipotential curve

$$r_1{}^2 = 2\mu ar,$$

where a is the radius of the circle (which is introduced for the sake of making the equation homogeneous), and μ is some ratio which is constant for the same curve.

With polar coordinates about the centre, taking a as the radius of the circle, we get

$$r^2 + a^2 - 2ar \cos\theta = 2\mu ar,$$
$$r^2 - 2ar(\mu + \cos\theta) + a^2 = 0 \ldots .$$

If $\mu =$ or > 2, the curve is a closed curve, and, when r is small compared with a, the curve nearly coincides with an ellipse of eccentricity $\frac{1}{\mu}$ and mean distance $\frac{\frac{1}{2}\mu a}{\mu^2 - 1}$:

$$r = \frac{a^2 + r^2}{2a\mu\left(1 + \frac{1}{\mu}\cos\theta\right)}.$$

Hence $\frac{r^2}{a^2}$ expresses the percentage of error in the value of r if the ellipse be taken instead of the curve.

In a circular disk of 100 millims. in radius the distance between the curve and the ellipse at a distance of 25 millims. from the centre of the disk is only about 1·5 millim.

When μ is less than 2 and greater than $(\sqrt{2} - 1)$, the curves are of double curvature, and have points of inflection.

From the equation of the curve we obtain

$$\{r - a(\mu + \cos\theta)\}\frac{dr}{d\theta} + ar\sin\theta = 0.$$

If $r=a$, then $\mu+\cos\theta=1$.

Hence $r\,.\,\frac{d\theta}{dr}=0$; and the curves generally cut the edge of the disk at right angles.

When $\mu=2$ and $\cos\theta=-1$, then the two branches of the curve meet on the edge at the extremity of the diameter through the two poles.

On this curve

$$r\,.\,\frac{d\theta}{dr}=\frac{\sqrt{(2+\cos\theta)^2-1}}{\sin\theta}=\frac{\sqrt{(1+\cos\theta)(3+\cos\theta)}}{\sin\theta}=\sqrt{\frac{3+\cos\theta}{1-\cos\theta}}.$$

Hence when $\cos\theta=-1$,

$$r\frac{d\theta}{dr}=\pm1,$$

and the two branches of the curve are each inclined at an angle of 45° to the edge of the disk.

The polar equation to this curve is very much simplified when this double point is taken as the origin of coordinates.

The polar equation then becomes

$$r^2+4a^2-4ar\cos\theta=4a\sqrt{r^2+a^2-2ar\cos\theta}\,.\,r^4-8ar^3\cos\theta$$
$$+16a^2r^2\cos^2\theta+8a^2r^2=16a^2r^2\,.\,(r-4a\cos\theta)^2$$
$$=8a^2\,.\,r=4a\cos\theta\pm2\sqrt{2}-a\,;$$

and $\frac{dr}{d\theta}=-4a\sin\theta$.

From this result it is easy to see that there is no point of inflection in the curve; so that each branch of the curve is continuous and remains on the same side of its tangent.

From the above equations the curve may be traced. It consists of two loops, which form a continuous curve, the two branches cutting one another at right angles in passing through the double point on the edge of the disk.

The complete equipotential curves for the unlimited sheet may also be readily traced from the above equations to those curves by giving different values to μ (see Plate 1. fig. 7).

Neglecting the part of the curve outside the disk, the equation to the curve may be put under the form

$$\frac{\{r-a(\mu+\cos\theta)\}}{a}=-\sqrt{(\mu-1+\cos\theta)(\mu+1+\cos\theta)}.$$

To find the points where it cuts the axis, let $\cos\theta=\pm1$; then

$$\frac{r}{a}=(\mu\pm1)-\sqrt{\mu(\mu\pm2)},$$

where the upper signs are to be taken together.

In the case when $\mu=2$,

$$\frac{r}{a}=3-2\sqrt{2} \text{ and } 1,$$

the distances being measured in opposite directions.

To find the change in the value of $\frac{r}{a}$ when μ has a slightly different value. Let

$$\mu=2+\frac{1}{30} \text{ suppose;}$$

then

$$\frac{r}{a}=3+\frac{1}{30}-\sqrt{\left(2+\frac{1}{30}\right)\left(4+\frac{1}{30}\right)}$$

$$=3-2\sqrt{2}+\frac{1}{30}-\frac{2\sqrt{2}}{80}=3-2\sqrt{2}-{\cdot}002 \text{ nearly,}$$

or

$$=1+\frac{1}{30}-\sqrt{\left(2+\frac{1}{30}\right)\cdot\frac{1}{30}}=1-\frac{\sqrt{61}-1}{30}=1-{\cdot}227 \text{ nearly.}$$

Hence if μ be increased by $\frac{1}{30}$, the curve cuts the axis at a distance of nearly one fourth of the radius from the singular point.

If μ is less than 2, the curve does not cut the axis on the negative side of the origin.

We may find where it cuts the edge of the disk by making $\frac{r}{a}=1$.

Let $\mu=2-\frac{1}{30}$;

then

$$\left\{1-2+\frac{1}{30}-\cos\theta\right\}=\sqrt{\left(1-\frac{1}{30}+\cos\theta\right)\left(3-\frac{1}{30}+\cos\theta\right)},$$

and

$$1-\frac{1}{30}+\cos\theta=0;$$

so that θ is very nearly 15°.

Hence a very small variation in the value of μ produces very great changes in those parts of the curve which are not near to the centre of the disk.

This is a point of very great importance in connexion with the tracing of equipotential curves on tinfoil or copper disks; and the uncertainty in the experimental determination of points in the neighbourhood of the singular point (see Case 6, p. 6) is entirely explained.

Supposing that one of the galvanometer-electrodes is placed on the straight line joining the two battery-electrodes at the point L in Plate 2. fig. 6. When the pin or electrode is 1 millim. in diameter the equipotential curve corresponding to one extremity of the diameter of the pin cuts the edge of the circular disk at a point 22° distant from the singular point, whilst the equipotential curve through the other extremity of the same diameter of the pin cuts the radius drawn to the singular point at a distance of more than one third of the radius from the singular point.

In order to draw the curves near the singular point correctly, both galvanometer-electrodes must be placed in contact with the disk in the neighbourhood of the singular point.

Electrical Distribution in Space of three dimensions.

To consider the laws of distribution of electricity in space of three dimensions, let a point or small sphere be charged with electricity; then, by Laplace's equation, the potential at any point at distance r from it is of the form $\frac{A}{r}$.

If there be two points with charges of electricity proportional to A and B, then the potential at any point is of the form $\frac{A}{r}+\frac{B}{r'}$, where r, r' are the distances from the point to the two charged spheres.

When the charges on the two spheres are equal, but of opposite kinds, the expression for the potential becomes $A\left(\frac{1}{r}-\frac{1}{r_1}\right)$.

The equipotential surfaces will then be surfaces of revolution about the straight line joining the two charged spheres. For an equipotential curve we shall have $\frac{1}{r}-\frac{1}{r_1}=\frac{1}{c}$.

On referring to the experiments with battery-electrodes immersed to a considerable depth in a conducting liquid, so as not to be near the boundary of the liquid, we see that the same equation is true for the equipotential surfaces when a steady current flows in at one electrode and out at the other.

The equation to an equipotential surface will be of the form

$$\frac{1}{r}-\frac{1}{r_1}=\frac{1}{c}.$$

Take a section of the surface through the axis, and refer the section to rectangular coordinates.

Let the axis of revolution be the axis of x, and a line equidistant from the electrodes be the axis of y, then the equation to the curve is

$$\{(x-a)^2+y^2\}^{-\frac{1}{2}}-\{(x+a)^2+y^2\}^{-\frac{1}{2}}=\frac{1}{c},$$

where $2a$ is the distance between the electrodes.

For a consecutive point in the same curve, we get

$$\frac{(x-a)\delta x+y\delta y}{r^3}-\frac{(x+a)\delta x+y\delta y}{r_1^{\,3}}=0,$$

$$\text{or } \left\{\frac{x-a}{r^3}-\frac{x+a}{r_1^{\,3}}\right\}\delta x+y\delta y\left(\frac{1}{r^3}-\frac{1}{r_1^{\,3}}\right)=0.$$

Hence for the line of flow through (xy) which will cut this curve at right angles,

$$\left(\frac{x-a}{r^3}-\frac{x+a}{r_1^{\,3}}\right)\delta y-\delta x\left(\frac{y}{r^3}-\frac{y}{r_1^{\,3}}\right)=0,$$

or

$$\frac{y^2\delta x-(x+a)y\delta y}{r_1^{\,3}}-\frac{y^2\delta x-(x-a)y\delta y}{r^3}=0,$$

or

$$\frac{\delta x}{r_1}-\frac{(x+a)\{(x+a)\,\delta x+y\delta y\}}{r_1^{\,3}}-\frac{\delta x}{r}+\frac{(x-a)\{(x-a)\delta x+y\delta y\}}{r^3}=0.$$

Integrating, we get

$$\frac{x+a}{r_1}-\frac{x-a}{r}=m, \text{ where } m \text{ is constant.}$$

The curve cuts the axis of y at a point where

$$\frac{a}{r}=\frac{a}{r_1}=\frac{m}{2}.$$

If a is the angle which the two radii drawn to the same point make with the axis when they are equal to one another, then $m=2\cos a$.

If ϕ and θ be the angles which the two radii drawn to any point in the curve make with the axis, then the equation to a line of flow may be written in the form

$$\cos\phi-\cos\theta=2\cos a.$$

This will be the equation to the line of flow in any plane through the two electrodes.

These lines of flow coincide with the lines of force in non-conducting space with equal and opposite charges in the positions of the two electrodes. They also coincide with the magnetic lines of force when the two poles are in the same positions as the electrodes. From this equation the form of the lines of flow may be readily drawn.

Let AB be the two electrodes, O the middle point of AB, and OE bisect AB at right angles.

Let E be a point on the line of force. Describe a semicircle on AB cutting AE in the point F.

Take AH equal to twice AF. Place AH in any position ANH cutting the circle in N, and take a chord BG equal to NH ; BG produced will meet AH on the line of force.

Fig. 6.

For
$$\frac{AN}{AB} = \cos\phi, \text{ and } \frac{BG}{AB} = \cos(\pi-\theta);$$

and
$$\frac{AN}{AB} + \frac{BG}{AB} = \frac{AH}{AB} = 2\cdot\frac{AE}{AB};$$

or
$$\cos\phi - \cos\theta = 2\cos\alpha.$$

We may regard the conducting-mass as divided into two parts by a plane passing through the axis of revolution of the lines of flow. The equipotential surfaces will all cut every such plane at right angles.

Hence we may suppose the conducting-mass on one side of such a plane to be removed without changing the form of the equipotential surfaces. The resistance of the conductor between the two electrodes will then be doubled.

Hence in a liquid the form of the lines of flow and equipotential surfaces will be the same when the electrodes are both in the surface of the liquid as when they are immersed to infinitely great depths in it. For the same reason, if the liquid be contained in a very large rectangular vessel with two plane sides parallel to the line joining the electrodes, the forms of the equipotential surfaces will be the same when the electrodes are on the line where the surface of the liquid meets one side of the box, provided they are not near the ends of the box, and provided the opposite side of the box is too far off to disturb the forms of the equipotential surfaces.

A particular solution of the equation to the lines of flow is

$$\cos\theta - \cos\phi = 1.$$

At one of the electrodes $\cos\phi = -1$, and hence $\theta = \frac{\pi}{2}$; and at the other $\cos\theta = 1$, and hence $\phi = \frac{\pi}{2}$; so that the lines of flow cut the axis at right angles, *i. e.* the lines of flow given by this equation touch the two planes drawn through the electrodes at right angles to the axis.

In order that the lines of flow in a vessel containing liquid may coincide accurately with the theoretical lines of flow in a liquid of infinite extent in all directions, it is necessary that every section of the boundary of the vessel through the electrodes should be a line of flow.

From the above considerations, it appears that near the electrodes the ends of the vessel may be plane and at right angles to the axis, without causing much change of form in the equipotential surfaces.

When there are charges of electricity at several points, then the potential at any other point is the algebraic sum of the potentials at that point due to the several charges separately.

This will also be the case in a liquid conductor of unlimited extent in every direction when currents enter and leave the liquid at several points at a great depth within it.

The potential at any point is of the form

$$\frac{e}{r}-\frac{e_1}{r_1}+\frac{e_2}{r_2}-\frac{e_3}{r_3}+\&c.$$

If the currents flowing out and in at the several points are all equal, then the potential is of the form

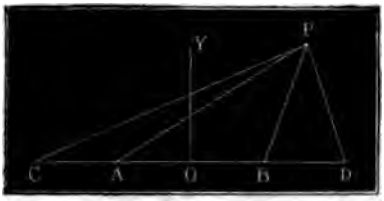
$$A\left(\frac{1}{r}-\frac{1}{r_1}+\frac{1}{r_2}-\frac{1}{r_3}+\&c\right).$$

If the electrodes are all in one plane, then this plane may be taken as one of the bounding surfaces of the conducting liquid, without altering the forms of the equipotential surfaces, which cut the plane always at right angles.

If r, r_1, r_2, r_3 are the distances of a point from the electrodes, then, with four electrodes, the equation to an equipotential surface will be

$$\frac{1}{r}-\frac{1}{r_1}+\frac{1}{r_2}-\frac{1}{r_3}=\frac{1}{c}.$$

Fig. 7.



Suppose the electrodes to be in the same straight line at A, B, C, D; and let AB$=2a$, and CD$=2b$; the positive electrodes at A and C, and the negative electrodes at B and D; then the equation to a section of an equipotential surface through the axis referred to rectangular coordinates, as before, will be

$$\{(x-a)^2+y^2\}^{-\frac{1}{2}}-\{(x+a)^2+y^2\}^{-\frac{1}{2}}+\{(x-b)^2+y^2\}^{-\frac{1}{2}} \\ -\{(x+b)^2+y^2\}^{-\frac{1}{2}}=\frac{1}{c_1}.$$

Differentiating, we get for a consecutive point

$$\frac{x-a+y\dfrac{dy}{dx}}{\{(x-a)^2+y^2\}^{\frac{3}{2}}}-\frac{(x+a)+y\dfrac{dy}{dx}}{\{(x+a)^2+y^2\}^{\frac{3}{2}}}+\&c=0.$$

Hence for a line of flow which cuts this at right angles,

$$\frac{(x-a)\dfrac{dy}{dx}-y}{\{(x-a)^2+y^2\}^{\frac{3}{2}}}-\frac{(x+a)\dfrac{dy}{dx}-y}{\{(x+a)^2+y^2\}^{\frac{3}{2}}}+\&c.=0.$$

Hence, multiplying by y and integrating as before, we get

$$\frac{x+a}{r_1}-\frac{x-a}{r}+\frac{x+b}{r_3}-\frac{x-b}{r_2}=c,$$

or

$$\cos\theta-\cos\phi+\cos\theta_1-\cos\phi_1=c,$$

where θ, θ_1, ϕ, ϕ_1 are the angles which the radii make with the line on which the electrodes lie.

If we examine the equation

$$\cos\theta+\cos\theta_1-\cos\phi-\cos\phi_1=c,$$

which gives the lines of flow where four electrodes are arranged symmetrically along a straight line, we see that when c is greater than 2, the curve does not cut either of the two planes given by the equations

$$\cos\theta+\cos\theta_1=0, \text{ or } \cos\phi+\cos\phi_1=0,$$

but lies entirely between them, and that it cuts the axis at the two interior electrodes. The curve

$$\cos\theta+\cos\theta_1-\cos\phi-\cos\phi_1=2$$

meets the plane $\cos\theta+\cos\theta_1=0$ where it cuts the axis; for $\cos\phi=-1$, and $\cos\phi_1=-1$ for this point.

When $\cos\theta+\cos\theta_1-\cos\phi-\cos\phi_1$ is less than 2, the curve cuts the planes $\cos\theta+\cos\theta_1=0$ and $\cos\phi+\cos\phi_1=0$ at some distance from the axis, and cuts the axis at the point from which θ_1 is measured, *i. e.* it cuts the axis at the two exterior electrodes.

The curve $\cos\theta+\cos\theta_1-\cos\phi-\cos\phi_1=2$ has very close contact with the plane $\cos\theta+\cos\theta_1=0$, since the distance between them depends on the differences of small quantities of the second order. Hence in a rectangular box, when the two electrodes are near to, but not in contact with the ends, the lines of flow and equipotential surfaces should very closely coincide with the lines of flow and equipotential surfaces in space, supposing that two additional like equal electrodes are placed at the electric images of the electrodes. (See Cases 7 and 8, on pp. 9 and 10.)

The value of the constant, c, in the above equation will determine directly the cosine of the angle at which the curve cuts the axis.

For at the axis $\cos\phi=-1$, $\cos\phi_1=-1$, and *either* $\cos\theta=-1$ when c is less than 2, in which case $\cos\theta_1=c-1$, and the curve cuts the axis at the exterior electrodes at an angle $\cos^{-1}(c-1)$,

r $\cos\theta_1=1$ when c is greater than 2, in which case $\cos\theta=c-3$,

nd the curve cuts the axis at the interior electrodes at an angle

$$\cos^{-1}(c-3).$$

As in the case of two electrodes, if any two planes, both intersecting along the line of the electrodes, be taken as bounding surfaces of the conducting liquid, there will be no change in the forms of the lines of flow and the equipotential surfaces. The resistance of the liquid will be versely proportional to the angle between two such bounding planes.

at.

A case of this kind occurs when the electrodes lie on the straight line where the surface of the liquid meets the plane vertical side of the vessel containing it.

Electrical Distribution with Linear Electrodes.

Next consider the case in which the electrodes are parallel straight lines, extending throughout the liquid. With one electrode, the potential at any point at a distance r from it is

$$C+A\log r.$$

When there are several electrodes, the potential is

$$C+A\log r+B\log r_1+\&c.$$

If the currents flowing into the liquid at the several electrodes are all equal, the potential is

$$C+A\,(\log r+\log r_1+\&c);$$

and for an equipotential surface we have

$$r\,r'\,r''\ldots=c\,r_{\prime}\,r_{\prime}'\,r_{\prime}''\ldots$$

where dashes below the letter indicate negative electrodes.

This equation is the same as that obtained for a plane conductor of small thickness, which has been already considered; and the forms of the equipotential surfaces are cylindrical. The disk of tinfoil may be considered as a particular case of the solid with electrodes throughout the whole thickness when that thickness is supposed to be small.

For two linear electrodes with equal and opposite currents, the equipotential surfaces will be circular cylinders, and the lines of flow will also be circular cylinders cutting them at right angles.

The particular cases of circular and other disks which have already been considered will give the sections of the equipotential surfaces for the corresponding cases with linear electrodes in the liquid, and will completely determine them.

Supposing the surface of the liquid to be of unlimited extent, and that a current enters by one line electrode, and leaves by equal currents at two negative electrodes, the forms of the cylindrical surfaces will be given by the equation

$$r^2=cr_1\,r_2.$$

When the positive electrode is at the middle point of one side of the rectangular box used in the experiments, and an equal negative electrode is within the box and near the same side, as in Case 10, the forms of the equipotential surfaces will be given by the equation

$$r^2=cr_1\,r_2;$$

r_1, r_2 are the distances of the point from the negative electrode and from its image.

This equation will give the form of the surfaces accurately only when the opposite side and the two ends of the box are far enough off that they may be regarded as practically at an infinite distance from the electrodes.

When $c=1$, the equation becomes $r^2=r_1 r_2$: so that the section of the cylindrical surface is a rectangular hyperbola.

A curve determined by experiment is drawn in Plate 2. fig. 12, very near to the position of this hyperbola; but as one of the electrodes was at the centre of the box, the forms of the equipotential curves will be slightly changed, because of the influence of the opposite side and ends of the box.

At the vertex the two curves coincide, and, measured along the latus rectum of the hyperbola, the distance between them is only 5 millims. Since the distance between the battery-electrodes is one half the breadth of the box, the influence of the opposite side and ends of the box will be quite sufficient to account for so small a difference. Thus we see that with linear electrodes there is a very satisfactory agreement between theory and experiment.

The equipotential curves for Case 10, with linear electrodes in the liquid, are theoretically the same as those for Case 5, with points on a sheet of tinfoil for electrodes. A comparison of the figures (Plate 1, fig. 5 and Plate 2. fig. 12) which are laid down from the experimental results shows how closely they agree, and may be taken to be an independent proof of the accuracy of the theory of electrical distribution.

November 18, 1875.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

In pursuance of the Statutes, notice of the ensuing Anniversary Meeting was given from the Chair.

Mr. Etheridge, Mr. F. Galton, Mr. Newmarch, Dr. W. Pole, and Mr. W. W. Smyth, having been nominated by the President, were elected by ballot Auditors of the Treasurer's Accounts on the part of the Society.

Mr. Robert Lewis John Ellery (elected 1873), Mr. James Geikie, Dr. Emanuel Klein, Prof. E. Ray Lankester, Mr. Robert Stirling Newall, and the Earl of Carnarvon were admitted into the Society.

The following extract from the Will of the late Sir Charles Wheatstone, F.R.S., in a letter from Mr. Robert Sabine, one of the executors, was read:—"I leave to the Royal Society of London for the Promotion of Natural Knowledge the Portrait of the Hon. Robert Boyle, and all the framed Portraits of scientific men now in my possession; and I also bequeath to the said Royal Society the sum of Five Hundred Pounds, to be applied to the purposes of the Wollaston Donation Fund."

Fig. 1.

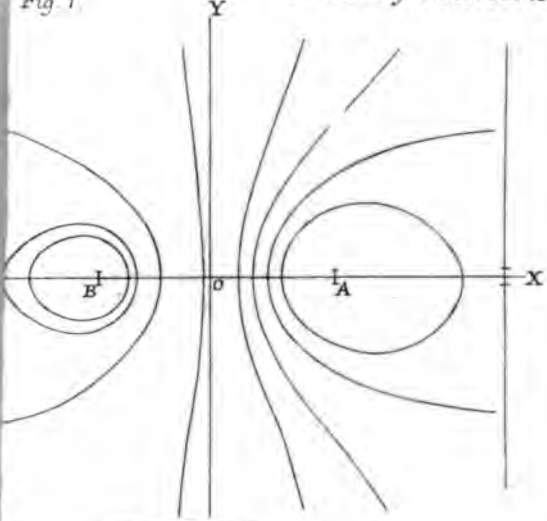


Fig. 7.

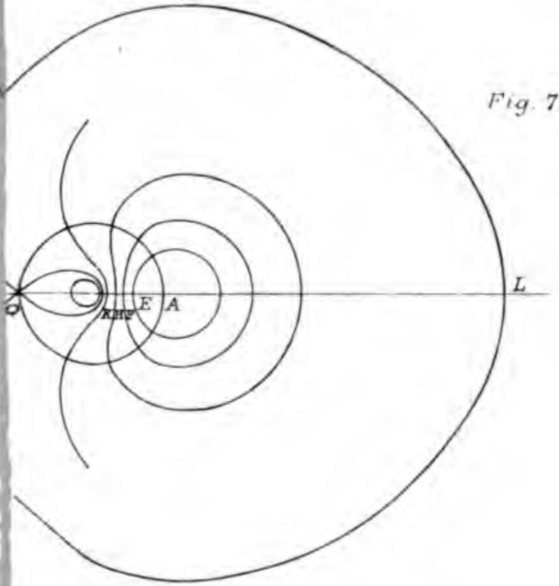
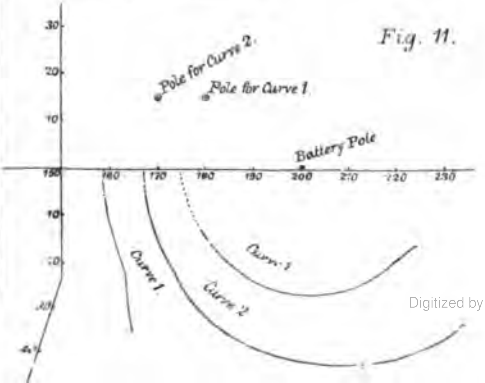


Fig. 11.



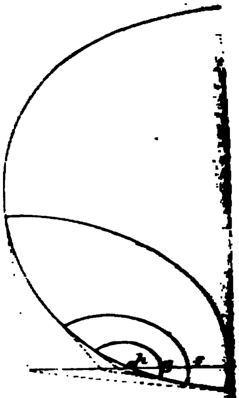


Fig. 6.

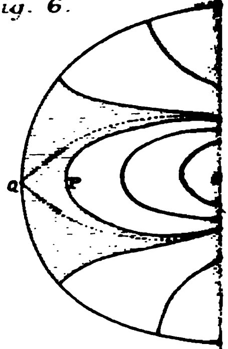
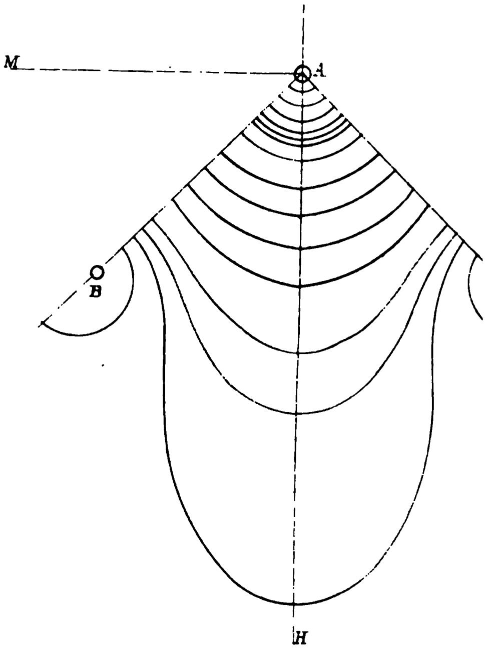
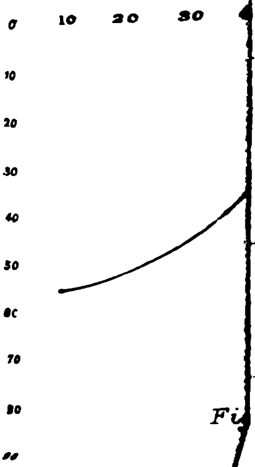


Fig. 4.





Fi

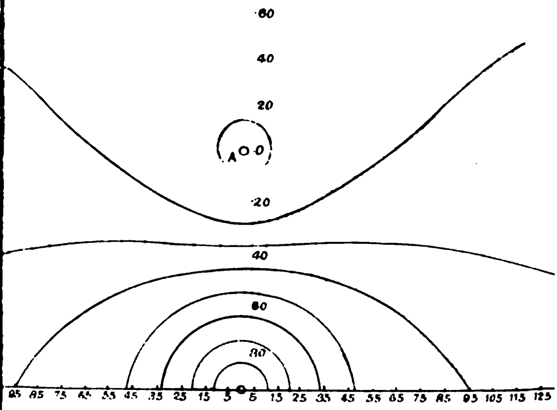


Fig. 12

W.H. Wesley Lith.

The President expressed his regret, which would be shared by the Society, that intelligence had been received by the Admiralty of the decease, at sea, of Dr. von Willemöes-Suhm, a distinguished young Naturalist attached to the Scientific Staff of the 'Challenger' Expedition.

The Presents received were laid on the table, and thanks ordered for them.

A direct-vision compound prism by Merz, the gift of Mr. Gassiot, was presented to the Society. It is regarded by the maker as one of remarkable excellence, and is composed of a central prism, of large angle, formed of peculiarly heavy lead glass, with opposed prisms of crown glass cemented to its two faces. It is capable of taking in a pencil of rays of 28½ lines in width. The indices of refraction, in the heavy glass, of Fraunhofer's lines C, D, E, F are given by M. Merz as follows:—

$$C_n = 1\cdot7389.$$
$$D_n = 1\cdot7513.$$
$$E_n = 1\cdot7621.$$
$$F_n = 1\cdot7723.$$

Hence the dispersion is almost double that of ordinary flint glass.

The following Papers were read:—

I. "Report to the Hydrographer of the Admiralty on the Cruise of H.M.S. 'Challenger' from June to August 1875." By Prof. WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff on Board. (Published by permission of the Lords of the Admiralty.) Received October 28, 1875.

[PLATES 3–7.]

Hilo Hawaii, August 18, 1875.

SIR,—The 'Challenger' left Yokohama on the 16th of June, and ran an easterly course between the parallels of 35° and 40° north latitude, as far as the meridian of 155° east. We then turned nearly directly southwards and reached Honolulu on the 27th of July. The weather throughout was sufficiently favourable; shortly after leaving Yokohama there was a good deal of swell, which interfered somewhat with our dredging-operations and caused the loss of a good deal of time; we established, however, 24 observing stations, at each of which most of the desired observations were made. On the 17th of June we sounded in 1875 fathoms, with a bottom of bluish-grey clay and a bottom-temperature of 1°·7 C., 40 miles to the south-east of No-Sima Lighthouse. The trawl was put over, and it brought up a large quantity of the bottom, which showed the clay was in a peculiar concretionary state, run together into coherent lumps, which were bored in all directions by an Annelid of the Aphroditacean group. In many cases the Annelids were still in the burrows. Among the clay there were large lumps of grey pumice. The trawl contained several fishes (belonging, as usual, chiefly to the family Macruridæ) and a large number of Echinoderms, chiefly flexible sea-urchins, ophiurids, and starfishes of the genus *Brisinga.* The hydroid zoophytes were represented by a very remarkable species, apparently referable to the genus *Monocaulon* of Sars, a *Corymorpha*-like solitary polyp with adelocodonic gonophores; but instead of being of the proportions usual in its group, the stem in one of our specimens measured upwards of seven feet in height, while the polyp-head was nine inches in diameter across the proximal row of tentacles. We afterwards got another fine example of the same species at a depth of 2900 fathoms (Station 248). The temperature of the surface of the sea stood during the day at nearly 23° C., considerably above the temperature of the air; and a serial sounding gave the isotherm of 10° C. at a depth of little more than 200 fathoms. We were therefore evidently under the thermic influence of the Japan current, which was found by observation to be running in an easterly direction at a rate of 1½ knot an hour. The thermometers registered a uniform temperature of 1°·7 C. from a depth of 1000 fathoms to the bottom. About twenty Albatrosses, of a nearly uniform brown plumage with whitish heads (probably the young of the common North-Pacific species in their second year's plumage), followed the ship.

On the following day there was a stiff breeze from the southward, with a heavy sea. We sounded, however, successfully in 3950 fathoms, our deepest sounding in the North Pacific—position by dead reckoning lat. 34° 43′ N., long. 144° 2′ E., with a bottom of "red clay." The gale continued on the 19th, and the weather prevented our attempting to trawl; but a sounding in 3625 fathoms and serial temperatures to 1500 fathoms were obtained. At both of the two latter stations the high surface-temperature was maintained; and the position of the isotherm of 10° C. at station 239, at a depth of nearly 300 fathoms, indicates that up to this point, at all events, there was no diminution in the influence of the "Kuro-Siwo."

On the 21st we sounded in 2900 fathoms, with a bottom of "red clay." An attempt was made to trawl; but the sea was still running high, and in hauling in the line parted.

The temperature-observations gave a singular result. The surface-temperature had fallen to 18°·2 C., and the belt of water above 10° C. was reduced in depth to considerably less than 100 fathoms, while all the isotherms, at all events to a depth of 400 fathoms, rose in proportion. There seems to be little doubt, from a comparison of the American temperature-results with our own, that this sudden diminution of temperature is due to a cold surface-flow from the sea of Okhotsk, probably through Pico Channel or Vries Strait. Very likely its effect may not be found to be constant; and at this season it possibly attains its maximum from the melting of the snow over the vast region drained by the Amoor and the Udi and Siberian rivers with a southern outflow.

June 23.—We sounded in 2300 fathoms, with a bottom of "red clay."

The trawl brought up a quantity of lumps of pumice, more or less altered and more or less coated with manganese. Animals of all the invertebrate groups were abundant, free, and attached to the stones; but the assemblage was in no way remarkable. At this station the effect of the cold current was already almost entirely lost, the isotherm of 10° C. having resumed its position at a depth of about 200 fathoms.

On the 26th of June we sounded in 2800 fathoms. Temperature-soundings were taken to the usual depth; and the dredging-line was then veered to about 3000 fathoms with a cwt. lead and one towing-net at the end, two nets 250 fathoms from the end, and two more at a distance of about 1000 fathoms. The line with the nets was slowly dragged along for a time with the drift of the ship and hauled in. On carefully washing the nets and examining their contents several forms were met with which apparently do not occur on the surface, particularly a number of species of a group which is, so far as we know, entirely undescribed. It seems to be intermediate between the Radiolarians and the Foraminifera, resembling the former in the condition and appearance of the sarcode and in the siliceous composition of the test, and the latter in external form. The broken tests of these organisms are extremely abundant in the "red-clay" soundings; a sufficient number of observations has not yet been made to enable us to say with certainty what is their bathymetrical distribution. On the 28th we adopted a plan which we find extremely convenient at great depths, when we have reason to feel tolerably certain as to what the depth is going to be within moderately narrow limits. The trawl was put over at daybreak, and the line veered to 3500 fathoms; and while the trawl was going down the sounding was taken, in the present case at a depth of 2900 fathoms with a bottom of "red clay." In this way the trawl reached the bottom, probably between 7° and 8° C., and we could allow it to drift quietly for at least six hours before beginning to haul in. From a zoological point of view this haul was remarkably successful; there were one or two Fishes, a *Scalpellum*, a number of Annelids (particularly a prominent Aphroditacean), Echinoderms of the genera *Pourtalesia*, *Archaster*, *Brisinga*, and *Antedon*, a fine species of *Cornularia*, several examples of *Fungia symmetrica*, and some *Actiniæ*. The general distribution of temperature remained much the same, the isotherm of 10° C. retaining its position near the 200-fathom line.

We trawled, on the 2nd of July, in 2050 fathoms, with a bottom of light brownish ooze with many *Globigerina*-shells. The bag brought up a number of lumps of pumice, and among them a very characteristic assemblage of deep-sea animals, the most interesting an undescribed species of *Hyalonema*, which occurred in considerable numbers and in an excellent state of preservation. The form of the sponge-body is almost spherical, with a comparatively small oscular opening, and the coil is much shorter than in *H. Sieboldi*, in the largest specimens not more than six inches in length. One remarkable point was that in no case was there a commensal *Palythoa* connected with this sponge; the coil was always perfectly clean. The spicules of the network and of the sarcode closely resemble those of the Japanese species, but they all present marked specific differences in detail of form.

July 3.—We sounded in 2530 fathoms, with a bottom of reddish-brown ooze ("red clay"), and took temperature-soundings; we afterwards veered the dredging-line to 1500 fathoms with tow-nets, and got many specimens of the usual deep-water Protozoa.

July 5.—We sent down the trawl and afterwards sounded in 2900 fathoms, and took serial temperatures. In the trawl, along with many other deep-sea forms, there was one fine specimen of the large solitary hydroid already referred to (Station 237).

On the 7th we sounded in 3000 fathoms, with the usual bottom of red clay; on the 9th in 3050 fathoms, and on the 10th in 2950 fathoms. The results of the dredgings for the last few stations had been so uniform, and the operation was rendered so critical by the heavy swell from the westward, that we did not consider it necessary to repeat it on every occasion.

On the 12th of July the trawl was lowered at a depth of 2740 fathoms. The net contained very few animals, and was greatly torn and frayed; but in a kind of pocket formed by an accidental folding of the net there were about a cwt. of black mammillated concretions, which, when they were poured out on the deck, had very much the appearance of potatoes. The external surface of the concretion was slightly rough, and a number of small animal forms, particularly a minute rhizopod in a membranous tube, nestled in the crevices. The nature of these concretions will be discussed hereafter.

On the 14th of July we reached the point lat. 38° 9′ N., long. 156° 25′ W., whence we turned southwards towards the Sandwich Islands. For the last few stations the temperature of the water had been gradually sinking, and the influence of the Japan current dying out; the isotherm of 10° C. was now only 100 fathoms below the surface. The depth at this point was 3115 fathoms; we put over the small dredge, as the nature of the bottom had latterly been so destructive to the trawl, and brought up manganese nodules, with a few small sponges and Bryozoa.

On the 17th of July we sounded in 3025 fathoms, the bottom still "red clay," and on the 19th in 2850 fathoms. A serial sounding taken at the latter station to 1500 fathoms showed a considerable rise in the temperatures near the surface, the isotherm of 10° C. having again sunk to a depth of 200 fathoms, and that of 15° C. corresponding with the 100-fathom line. On the 21st the bottom was "red clay" at a depth of 2950 fathoms; the small dredge was lowered and brought up a large quantity of the ooze, very smooth and tenacious, but containing scarcely a trace of living things. The serial temperature-soundings indicated a still further rise in the temperature of the upper layers, due doubtless to progress southwards.

On the 23rd we sounded in 2875 fathoms, and on the 24th in 2775, the bottom in both cases having much the same character which it had maintained throughout the cruise. The Albatrosses, which had followed the ship, to the number of from fourteen to twenty daily, since we left Japan, left us to-day. We saw one or two Boatswain Birds (*Phaëton rubricauda*), and a Turnstone (*Strepsilas interpres*) flew about the ship for some hours, lighting on the combings and the rigging. On the 26th we sounded in 2225 fathoms; and on the morning of the 27th we passed into the strait between the islands of Molokai and Oahu, and trawled on hard ground in 310 fathoms, with but little success. In the evening we anchored in the harbour of Honolulu.

This cruise naturally divides itself into two parts:—a section about 3170 nautical miles in length, including the stations from No. 237 to No. 253, very slightly to the northward of east, between the parallels of 35° and 38° N. lat.; and a meridional section of 1128 nautical miles, along the meridian of 155° W. long. The first of these sections corresponds very closely in relative position with the section in the Atlantic between Sandy Hook and the Açores, and the points of resemblance and difference between them, when fully worked out, must prove most instructive. The two sections cross the two great deflections to the northward of the equatorial current, in the Atlantic the Gulf-stream, and in the Pacific the "Kuro-Siwo;" and the thermic influence of the two currents is fairly contrasted. The influence of the Gulf-stream, if not absolutely greater (and this is a point which it will be somewhat difficult to determine), is at all events much more concentrated and effective, owing to the continuity of the coast-line of the American continent, to the way in which the water of the equatorial current is driven into the Gulf of Mexico and superheated there, afterwards to be kept together and ejected in a defined stream through the Strait of Florida, and to the absence of periodical winds in the Atlantic. In the Pacific, on the other hand, the main flow of the equatorial current is weakened among the passages of the Malayan archipelago; and although a large part of it is directed northwards by the broken barrier formed by the Fiji Islands, the New Hebrides, and Papua, it almost at once enters the region of the monsoons, where it is thwarted for half the year; and it can only be regarded as comparable with that portion of the reflux of the Atlantic equatorial current which passes outside the West-Indian Islands. Nevertheless it passes the south coast of Japan as a very palpable and apparently a permanent current, exercising a very perceptible thermic influence to a depth of at least 300 fathoms.

In traversing the Pacific the influence of the Japan current appears to be gradually lost; while I am still inclined to believe that in the Atlantic the Gulf-stream is banked down against and reflected from the western coast of Europe. It is a question of great complexity; but it seems to me that it is consistent with our experience that the temperature of the water of the ocean at any one place is due, in a great measure, to the temperature of the source of that water—not entirely due, for in passing through a long distance the temperature of even the greatest masses of water is certainly gradually altered by conduction and mixture.

The suggestions of Dr. Carpenter and Mr. Buchanan that the existence of a deep layer of warm water in the Atlantic might be connected in some way with the mean annual temperature of the area and the absence of ocean-currents, are very suggestive; and I looked forward with great interest to an opportunity of testing them in the corresponding position in the Pacific. But there seems to be no trace of any thing of the kind; as the influence of the equatorial reflux becomes weaker the temperatures fall uniformly.

To show that the conditions in the two oceans differ more in degree than in kind, I give in Plates 3 and 4 curves constructed from serial soundings along nearly corresponding lines in the Atlantic and Pacific. Curves A and B are added on Plate 3 to show the position of the deeper belt of abnormally warm water which makes its appearance near the coast of Europe.

Plate 3.

No. of Station.	North-Atlantic Ocean.		Depth in fathoms.
	Latitude.	Longitude.	
43	36° 23′ N.	71° 51′ W.	....
44	37 25 ,,	71 40 ,,	1700
53	36 30 ,,	63 40 ,,	2650
65	36 33 ,,	47 58 ,,	2700
69	38 23 ,,	37 21 ,,	2200
71	38 18 ,,	34 48 ,,	1675
80	35 3 ,,	21 25 ,,	2660
A A	In the Bay of Biscay.		2090
B B	Off the coast of Portugal.		1090

Plate 4.

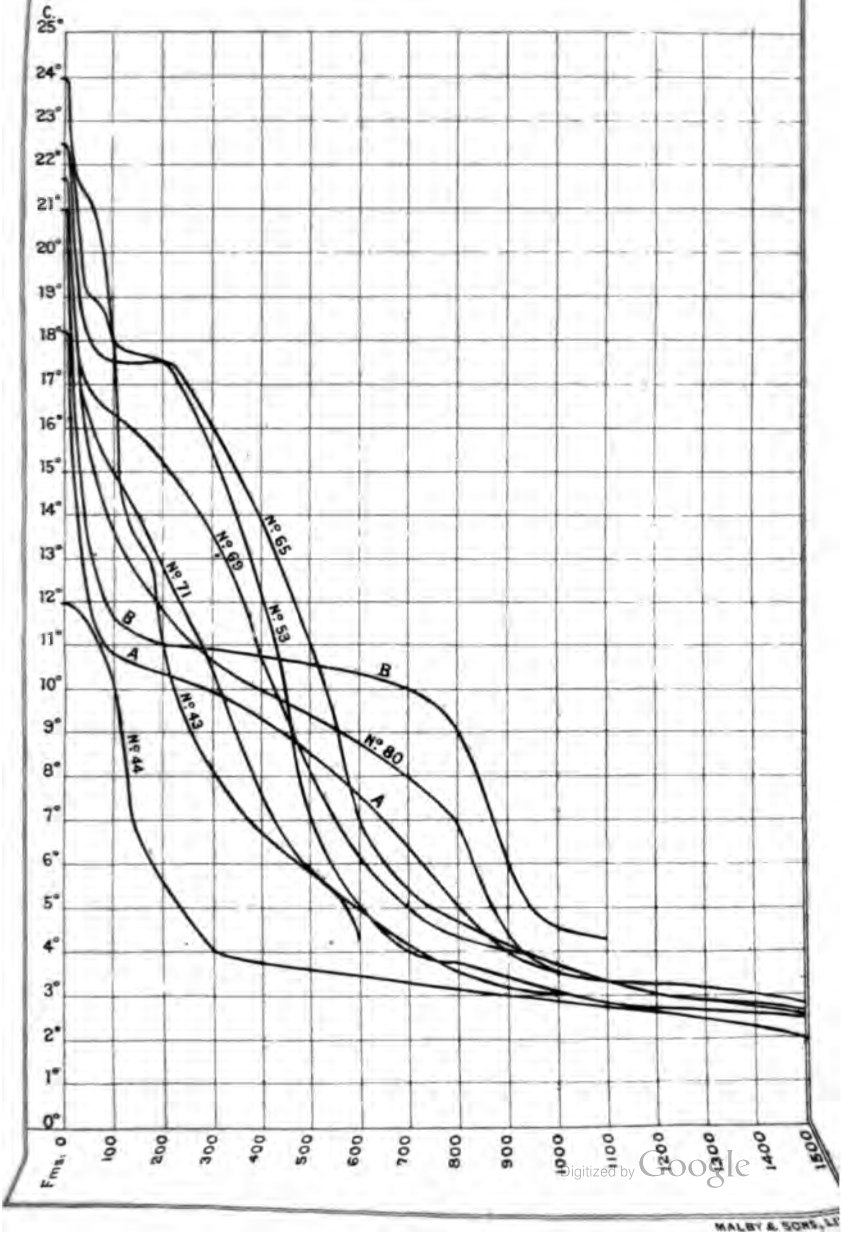
No. of Station.	North-Pacific Ocean.		Depth in fathoms.
	Latitude.	Longitude.	
237	34° 37′ N.	140° 32′ E.	1875
240	35 20 ,,	153 39 ,,	2900
243	35 24 ,,	166 35 ,,	2800
245	36 23 ,,	174 31 ,,	2775
246	36 10 ,,	178 0 ,,	2050
248	37 41 ,,	177 4 W.	2900
252	37 52 ,,	160 17 ,,	2740

There seems to be little doubt that the enormous mass of cold water which fills up the trough of the Pacific is, like the cold bottom-water of

Thomson.

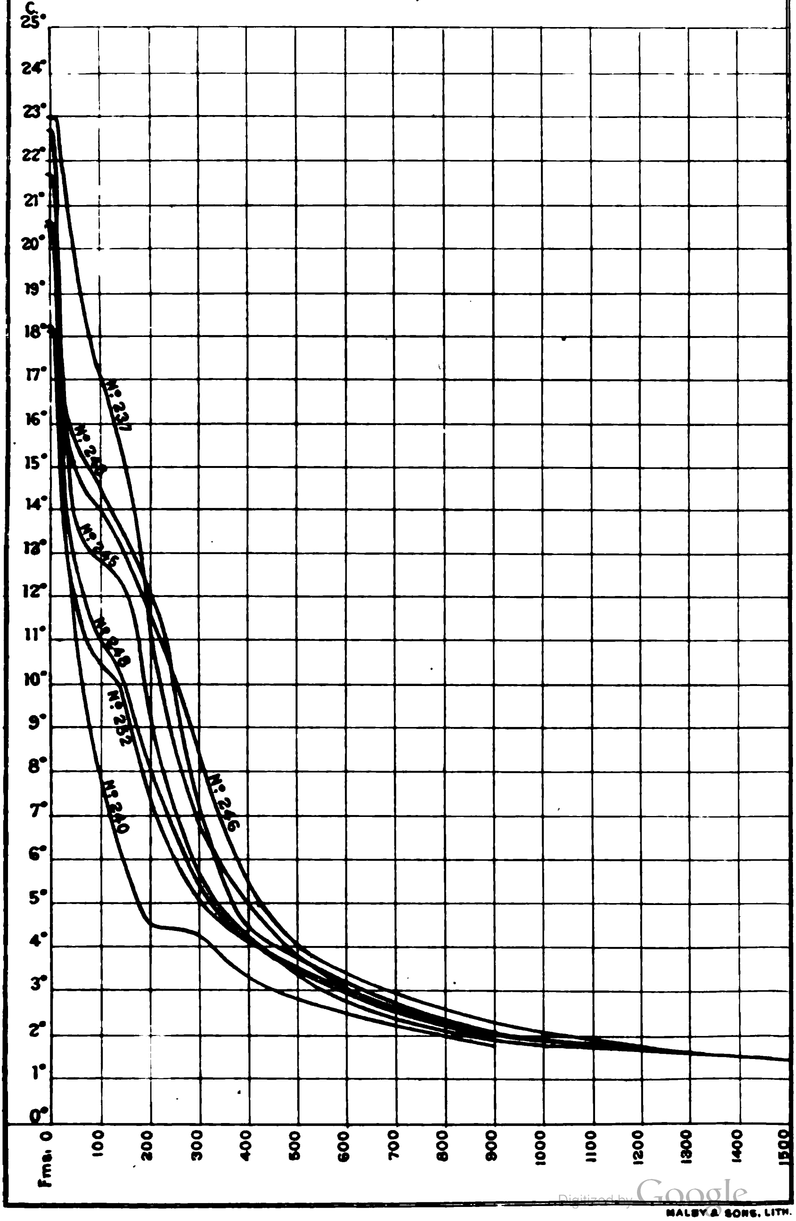
Proc. Roy. Soc. Vol. 24, Pl. 3.

CURVES CONSTRUCTED FROM SERIAL TEMPERATURE SOUNDINGS IN THE NORTH ATLANTIC.



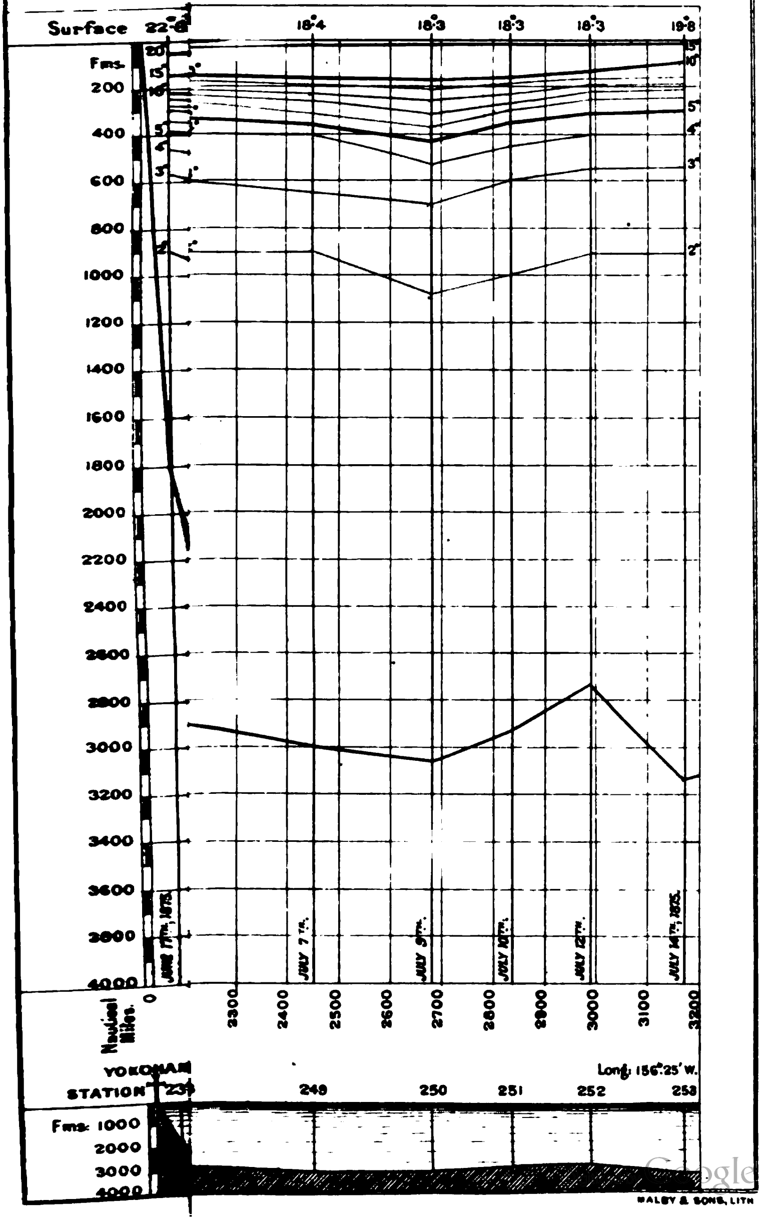
MALBY & SONS, LI

CURVES CONSTRUCTED FROM SERIAL TEMPERATURE SOUNDINGS IN THE NORTH PACIFIC.



MALBY & SONS, LITH.

TEMPERATURE
ON 253.



WALEY & SONS, LITH.

TEMPERATURE ON 253.

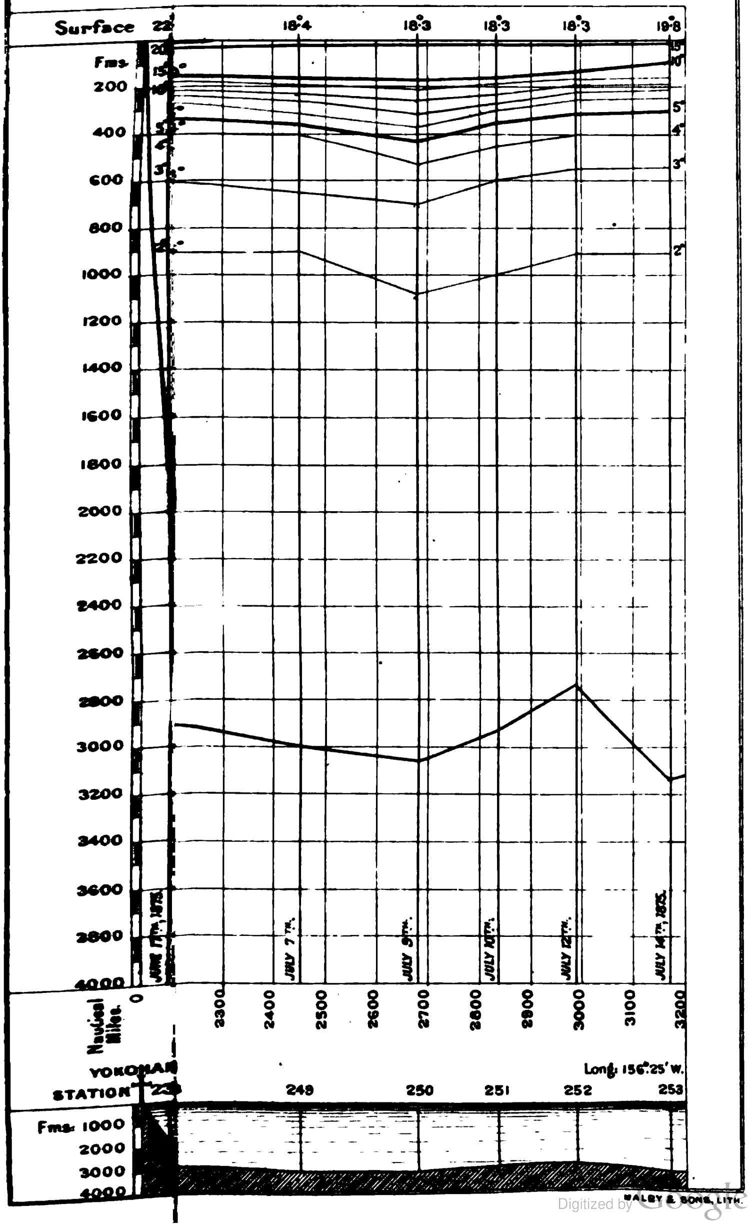
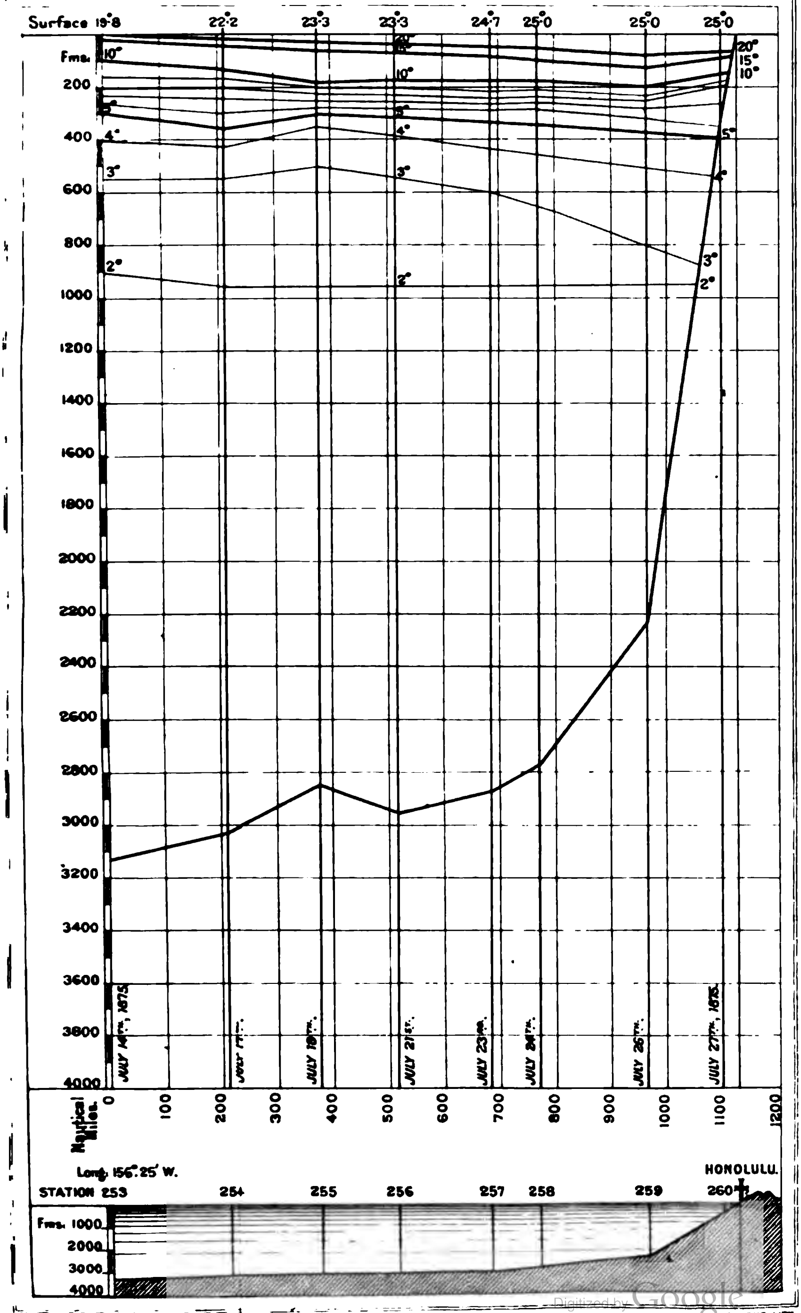
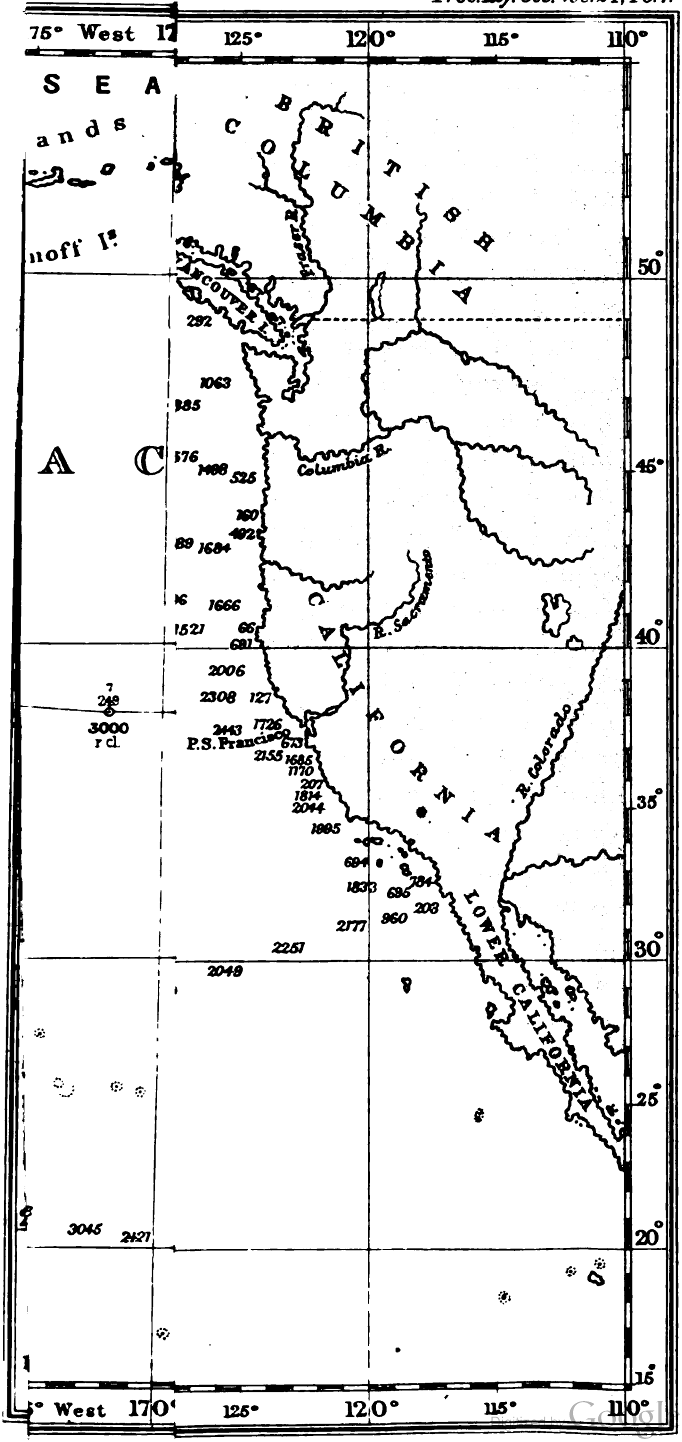


DIAGRAM SHOWING THE VERTICAL DISTRIBUTION OF TEMPERATURE BETWEEN STATION 253 AND HONOLULU.



MALBY & SONS, LITH.


75° West 17
125°
120°
115°
110°
S E A
ands
noff Is
BRITISH COLUMBIA
Fraser R.
VANCOUVER I.
50°
292
1063
385
A C
576
1488
525
Columbia R.
45°
160
492
189
1684
1666
1521
66
681
CALIFORNIA
R. Sacramento
40°
2006
2308
127
7
249
3000
r cl.
2443
1726
P. S. Francisco
673
2155
1686
1170
207
1814
2044
1885
R. Colorado
35°
694
1833
695
784
203
960
2177
2251
2048
LOWER CALIFORNIA
G. of
30°
25°
3045
2421
20°
15°
West 170°
125°
120°
115°
110°

the Atlantic, an indraught from the Southern Sea. The more the question is investigated the less evidence there seems to me to be of any general ocean circulation depending upon differences of specific gravity. It seems certain that, both in the Atlantic and in the Pacific, the bottom-water is constantly moving northwards; and I am now very much inclined to refer this movement to an excess of precipitation over the water-hemisphere, a portion of the vapour formed in the northern hemisphere being carried southwards and precipitated in the vast southern area of low barometric pressure. I hope to enter fully into the discussion of this matter on a future occasion. The temperature of the water is greatly lower in the Pacific for the first thousand fathoms than in the Atlantic in the corresponding latitude of 35° N. There is one very remarkable difference between the two basins: while in the Atlantic it seems certain that the temperature sinks gradually, though very slightly, for the last thousand fathoms to the bottom, it appears that in the Pacific the minimum temperature of 1°·7 C. is reached at a depth not greater than 1400 fathoms, and that from that depth to the bottom the temperature is the same.

The soundings from Yokohama to Honolulu are remarkably uniform in depth, the twenty-two soundings on one line, which are unaffected by the neighbourhood of land, giving an average of 2858 fathoms. The nature of the bottom is also very uniform; and, according to the nomenclature which we have adopted, it is, in each case, noted on the chart as "red clay." It is usually, however, somewhat greyer in colour than the typical "red clay," and contains a large proportion of the tests of siliceous organisms (a proportion which increases with increasing depth), and a considerable quantity of pumice in different states of comminution and decomposition. The clay contains scarcely a trace of carbonate of lime, although the surface swarms with ooze-forming foraminifera. In some cases the trawl came up half full of large lumps of pumice, which seemed to have been drifted about till they were water-logged, and to be softening and becoming decomposed; these pieces of decomposing pumice were often coated and pervaded throughout with oxide of manganese. Over the whole area the red clay was full of concretions, consisting mainly of peroxide of manganese, round, oval, or mammillated and very irregular, varying in size from a grain of mustard-seed to a large potato. When these concretions are broken up, they are found to consist of concentric layers having a radiating fibrous arrangement, and usually starting from a nucleus consisting of some foreign body, such as a piece of pumice, a shark's tooth, or a fragment of any organism—as, for instance, in one case a piece of a Hexactinnelid sponge of the genus *Aphrocallistes*, which was preserved as a very beautiful fossil in the centre. The concretions appear to form loose among the soft clay; the singular point is the amount of this manganese formation, and the vast area which it covers.

We were particularly successful, during this cruise, in getting good samples of the fauna from great depths; and we found that the fauna of the North Pacific, at depths of from 2000 to 3000 fathoms, although not very abundant in species, is by no means meagre. In each of six dredgings and trawlings at depths greater than 2000 fathoms we found, along with a few Fishes, a fair representation of all the larger invertebrate groups; and in one dredging, No. 253, at a depth of 3125 fathoms, we took a small Sponge, a species of *Cornularia*, an *Actinia*, an Annelid in a tube, and a Bryozoon. We were again struck with the wonderful uniformity of the fauna at these depths; if not exactly the same species, very similar representatives of the same genera occur in all parts of the world.

I am glad to be able to report that every thing is going on in a satisfactory way in the departments under my charge.

I have the honour to be, Sir,
Your obedient Servant,
C. WYVILLE THOMSON,
Director of Civilian Scientific Staff on board H.M.S. 'Challenger.'

Captain Evans, C.B., F.R.S.,
Hydrographer, Admiralty.

II. "On the Physiological Action of Vanadium." By JOHN PRIESTLEY, Platt Physiological Scholar, the Owens College, Manchester. Communicated by Prof. GAMGEE, F.R.S. Received June 18, 1875.

(Abstract.)

The author has divided his paper into four sections.

In the first the subject is introduced by a brief statement of the relationships of vanadium to other elements of the same and of allied groups; and the main object of the research is set forth, viz. by an extended investigation to endeavour to fix the physiological relationships of vanadium to the closely allied elements arsenic and phosphorus, so as to throw some light on the relations which probably exist between the chemical and physiological properties of the elements. The tribasic sodium vanadate (Na_3VO_4) is stated to have been the compound of vanadium made use of throughout the research, and the reasons of the preference are given.

In the second section the action of solutions of sodium vanadate upon simple organisms is shortly illustrated by the details of four sets of experiments, from which the conclusion is drawn that all solutions, except those which are extremely dilute (*i. e.* which contain only so much salt as corresponds to ·01–·5 per cent. of V_2O_5), act injuriously upon the simpler organisms.

In the third section the effects of vanadium in the above combination on complex organisms are discussed under two heads, viz.:—

A. The general action on the animal system when introduced by

subcutaneous injection, by injection into veins, or by injection into the alimentary canal.

B. the special action on the various functions of the animal body.

Under A thirty-one experiments are detailed, in which frogs, a pigeon, guineapigs, rabbits, dogs, and cats were made use of. From these experiments it is gathered:—

(1) That vanadium is a poisonous substance.

(2) That the symptoms of poisoning are, in general, similar whatever the method of the introduction of the salt into the animal system.

(3) That the symptoms of poisoning which appeared in one or other of the various classes of animals above mentioned are:—paralysis of motion; convulsions, local or general; rapidly supervening drowsiness, or indifference to external circumstances; congestion of alimentary mucous membranes; discharge of sanguinolent fluid fæces; presence of glairy, fluid mucus in the intestines after death; certain changes in respiration and, coincidently, a fall in temperature; drowisness and feebleness of pulse. In addition, the heart was always irritable after death, consciousness and sensibility to pain seemed unimpaired, and no diminution could be detected in the powers of muscle and nerve to respond to stimulation.

(4) That the lethal dose for rabbits lies between 9·18 mgr. and 14·66 mgr. of V_2O_5 per kilog. of rabbit.

Under B the author details a number of experiments undertaken with the view to gain more exact information as to the action of the salt of vanadium upon particular functions. The methods of experiment and the precautions observed are fully described; and the action on the following functions is discussed, viz.:—

(i) On the function of muscular tissue (after direct *local* application of the salt); and

(ii) On the function of nervous tissue (after direct *local* application of the salt). Five series of experiments are recorded, from which it appears that, under the conditions of the experiments, functional death of muscular and nervous tissue speedily follows even when the solutions used contain no more salt than corresponds to ·05 per cent. of V_2O_5.

(iii) On the function of circulation. Twelve experiments are recorded in which either subcutaneous or venous injection was employed, the experiments being performed on—

(*a*) Normal rabbits,

(*b*) Rabbits with divided vagi,

(*c*) Rabbits with divided cords,

(*d*) A frog with heart exposed and the nervous structures in front of the atlanto-occipital articulation destroyed.

From these it is gathered that sodium vanadate causes—

(1) A diminution of blood-pressure which is not continuous, but intermits during the operation of the poison;

(2) A disappearance of respiration-curves;

(3) A diminution and irregularity of pulse, which is also intermittent.

The results are discussed and considered to be due to an action of the poison on the vaso-motor centre and on the intracardiac nervous mechanism.

(iv) On the function of respiration. Subcutaneous or venous injection was again employed in the cases of seven rabbits, normal or with divided vagi. The results show that sodium vanadate causes—

(1) A stimulation, followed by

(2) A depression, of respiration, the latter being not continuous but intermittent; they are discussed and considered to be due to an action of the poison upon the respiratory nervous centre.

(v) On the functions of muscle and nerve. Subcutaneous injection was employed in the nineteen experiments described, which were performed on frogs, guineapigs, and rabbits. Tables are inserted illustrating diagrammatically the action of the salt. The results of these experiments are found to be the same as those given under A, where the general symptoms of poisoning by sodium vanadate are enumerated; and it is concluded, from the facts here stated, that the cause of the nervous symptoms is an action of the vanadate upon the central system of the spinal cord and medulla oblongata, and not upon nerve-trunks of peripheral terminations or upon muscle.

In the fourth section the chief results of the research are gathered up and briefly enumerated.

III. "On some Elementary Principles in Animal Mechanics. No. VII. The Law of Fatigue." By the Rev. Samuel Haughton, M.D. (Dubl.), D.C.L. (Oxon.), F.R.S., Fellow of Trinity College, Dublin. Received June 21, 1875.

The approximate law of muscular action, which I have called the law of fatigue, is thus expressed:—"*When the same muscle (or group of muscles) is kept in constant action until fatigue sets in, the total work done multiplied by the rate of work is constant.*"

The following experiments, in illustration of this law, were performed in Trinity College during the spring of the present year.

I instructed a number of medical students, chosen at random, to raise dumbbells of varying weight, one in each hand, in the tranverse plane, with hands supinated, raising and lowering the weights in equal times regulated by the beat of a pendulum. This process was continued until the distress of the fatigue produced became intolerable, and the number of times each weight was lifted was noted. The students were required to count "one—two" in time to the beat of the pendulum, so as to prevent them from counting the total number of lifts of the weight. Professor Macalister assisted me in these experiments; and one of us counted the number of lifts, while the other compelled the experimenters to observe the conditions of the experiment, which were:—

1. To keep time with the pendulum.
2. To raise the weight in the transverse plane.
3. To supinate the hands.
4. To abstain from all bending of the knees or spinal column.

The last three conditions are essential, in order to confine the work done strictly to the same muscles, which, in this case, are the *acromial deltoid* and *supraspinatus* muscles, whose average weight in the living subject is about 5·5 oz. av.

The experimenter must be carefully watched, in order to ensure the observance of these conditions; for he is impelled instinctively and unconsciously, by pain, to bring in other muscular fibres to aid those which are suffering from the constrained and regulated motion. If this be permitted, the law of fatigue will appear to be violated; for of the muscular fibres actually employed in doing work, some are quite tired out and others not; whereas the law of fatigue applies only to groups of muscles all of which are completely exhausted.

For each experiment I chose twenty students at random, using altogether about fifty different students; and no individual was experimented upon again until an interval of forty-eight hours had elapsed. The object of this arrangement was to avoid the effects of "training." In my first Table I give the mean result of twenty different students; and in my second Table I have selected one student, set aside for the purpose, and experimented upon once a week, so as to prevent the influence of "training." In all cases there were three well-marked stages:—

1. The work done with ease.
2. Accompanied by respiratory distress.
3. Accompanied by pain in the muscles used.

During the last stage great care must be taken to prevent changes in the posture and mode of motion, by which additional muscular fibres may come in aid of the fibres nearly fatigued.

Let W denote the total work done, and T the time of doing it; then, by the law of fatigue,

$$\frac{W^2}{T} = \text{constant}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If w be the weight held in the hand, and a be half the weight of the arm, and n the number of times the weights are lifted; since the time of raising and lowering the arms is constant, n is proportional to T, and the law of fatigue gives the formula

$$(w+a)^2 n = A, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where A is an unknown constant. In the following Table I give the values of w and the mean value of n for twenty distinct persons. The time of lift is in all cases *one second.*

Table I. Mean of Twenty Experiments.

No.	w.	n (obs.).	n (calc.).	Diff.
	lbs.			
1.	2·56	131·80	128·0	+3·8
2.	4·25	87·55	78·3	+9·2
3.	5·87	47·35	53·5	−6·2
4.	6·87	40·25	43·7	−3·5
5.	7·75	34·60	37·1	−2·5
6.	9·75	27·15	26·8	+0·3
7.	14·00	17·20	15·4	+1·8

The column containing the calculated values of n was obtained from equation (2) by using the values

$$a = 3{\cdot}50 \text{ lbs.},$$
$$A = 4699.$$

These values were obtained by finding the value of a, which renders A most nearly a constant, or

$$\frac{\delta A}{A} = \text{minimum.}$$

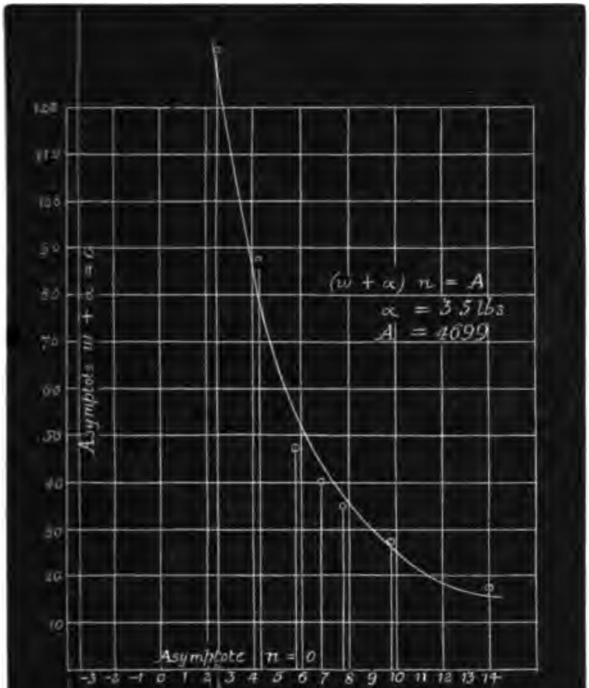
This Table gives 7 lbs. for the mean weight of the arm of all experimented on, a result which accords with the known facts.

In Table II. I give the results obtained from a single student, as already described, each value of n being a mean of several experiments, closely concurrent.

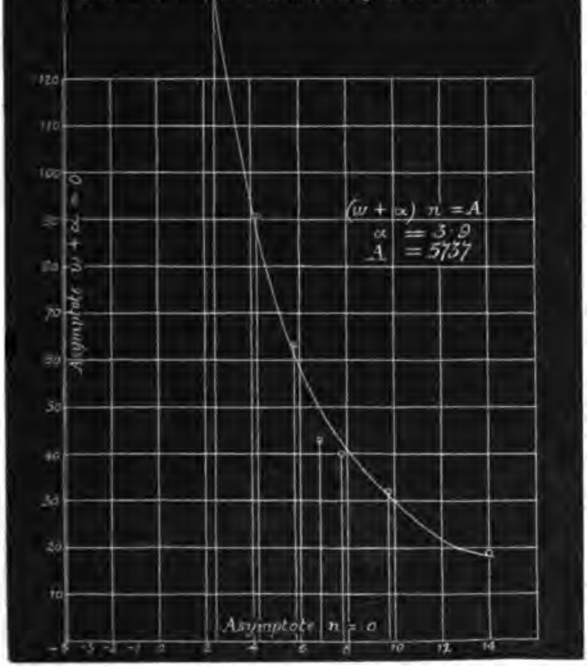
Table II. Mr. Samuel Warren.

No.	w.	n (obs.).	n (calc.).	Diff.
	lbs.			
1.	2·56	140·0	137·5	+2·5
2.	4·25	91·0	86·4	+4·6
3.	5·87	63·0	60·1	+2·9
4.	6·87	43·0	49·0	−6·0
5.	7·75	40·0	42·5	−2·5
6.	9·75	32·0	31·0	+1·0
7.	14·00	18·5	17·9	+0·6

No. I.


(w + α) n = A
α = 3.5 lbs
A = 4699
Asymptote w + α = 0
Asymptote n = 0
120
110
100
90
80
70
60
50
40
30
20
10
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

No. II.


(w + α) n = A
α = 3·9
A = 5737
Asymptote w + α = 0
Asymptote n = 0
120
110
100
90
80
70
60
50
40
30
20
10
-3 -2 -1 0 2 4 6 8 10 12 14

The calculated values of n were found from equation (2), using the values

$$a = 3{\cdot}9 \text{ lbs.},$$
$$A = 5737,$$

which were obtained from the principle of least variation of A, or

$$\frac{\delta A}{A} = \text{minimum}.$$

In the accompanying diagrams I. & II. (p. 45) I have plotted the cubical hyperbola represented by equation (2), and also the several observations, which lie sufficiently near the curve to justify me in considering the law of fatigue to be a first approximation to one of the fundamental laws of muscular action. I have elsewhere* shown that the law of fatigue corresponds with other experiments based on different data.

If we consider the *useful work* only, we have, from equation (2),

$$\text{useful work} = wn = \frac{Aw}{(w+a)^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

This equation represents a cuspidal cubic, whose ordinate has a maximum value, when $w = a =$ half the weight of the arm.

The foregoing observations are in accordance with this deduction, as may be seen from Table III.

TABLE III. Useful Work.

No.	w.	wn (20 experiments).	wn (Mr. Warren).
	lbs.		
1.	2·56	338	358
2.	4·25	372	387
3.	5·87	277	370
4.	6·87	276	295
5.	7·75	268	310
6.	9·75	264	312
7.	14·00	241	250

---

* Principles of Animal Mechanics. London, 1873.

November 25, 1875.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

In pursuance of the Statutes, notice was given from the Chair of the ensuing Anniversary Meeting, and the list of Officers and Council proposed for election was read as follows:—

President.—Joseph Dalton Hooker, C.B., M.D., D.C.L., LL.D.

Treasurer.—William Spottiswoode, M.A., LL.D.

Secretaries.— { Professor George Gabriel Stokes, M.A., D.C.L., LL.D.
Professor Thomas Henry Huxley, LL.D., Ph.D.

Foreign Secretary.—Professor Alexander William Williamson, Ph.D.

Other Members of the Council.—Professor J. Couch Adams, LL.D.; Major-General John T. Boileau; Edward Viscount Cardwell, F.G.S.; Warren De La Rue, D.C.L.; Captain Frederick J. O. Evans, R.N., C.B.; Edward Frankland, D.C.L.; Albert C. L. G. Günther, M.A., M.D.; Professor T. Wharton Jones, F.R.C.S.; Joseph Norman Lockyer, F.R.A.S.; The Rev. Robert Main, M.A.; Professor Daniel Oliver, F.L.S.; Professor Edmund A. Parkes, M.D.; Right Hon. Lyon Playfair, C.B., LL.D.; William Pole, C.E., Mus. Doc.; The Rev. Bartholomew Price, M.A.; Warington W. Smyth, M.A.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Replacement of Electro-positive by Electro-negative Metals in a Voltaic Cell." By J. H. GLADSTONE, Ph.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and ALFRED TRIBE, Esq., Lecturer on Chemistry in Dulwich College. Received July 31, 1875.

It is well known that one metal exerts a greater chemical force than another, and is capable of displacing it from its combinations. Among those metals with which we are familiar, potassium is looked upon as the most powerful; and it is a certain fact that calcium, barium, strontium, aluminium, and magnesium have been isolated by its agency. It could scarcely be expected, therefore, that any other metal could directly replace potassium. If such should happen, we would have an instance of reversal, and should expect to find, on examination of the conditions, an agent capable of doing just the reverse work of what is usually assigned to affinity.

It is also well known that in a simple voltaic cell, such as zinc connected with platinum in dilute hydrochloric acid, the more powerful or electro-positive metal zinc displaces the hydrogen that is in combination with chlorine, and the hydrogen makes its appearance against the less powerful or electro-negative metal platinum. The chemical theory of galvanism supposes that the force originates in the chemical action which takes place between the zinc and the acid; the contact theory supposes that it originates in some unexplained manner in the opposite electrical condition of the two metals induced by their contact. If the chemical theory be the true one, it is evident that a zinc-platinum cell can only become active when the binary liquid contains hydrogen or some metal which is less powerful than zinc. If, for instance, we were to employ a potassium salt instead of a hydrogen compound, it is inconceivable, on the pure chemical theory, that there should be any action at all.

Such an action, however, does take place if we substitute an aqueous solution of the chloride of potassium for the hydrochloric acid; the zinc combines with the chlorine, and the potassium is set free in some form, against the platinum, manifesting itself by the presence of free alkali and hydrogen gas. The same holds good with aqueous solutions of chloride of sodium or ammonium, or barium, strontium, calcium, or magnesium.

This action is slow; but if magnesium be used instead of zinc, it takes place sufficiently rapidly to be easily observed, and we have therefore studied the action of platinum and magnesium in connexion.

Experiments with Potassium Chloride.

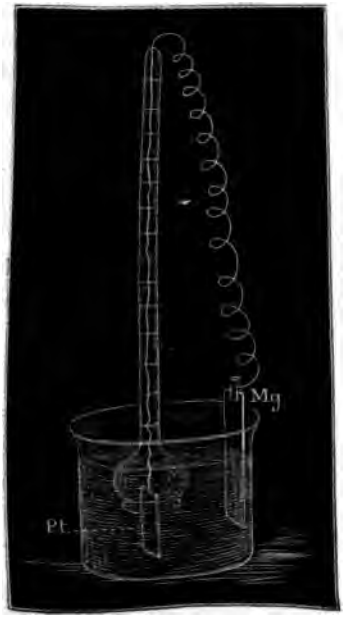
The solution employed was neutral to test-paper, and contained 5 grms. of salt in 100 cub. centims. of water. A strip of magnesium connected with one of platinum was immersed in such a way that the two metals remained about $\frac{3}{4}$ inch apart. Bubbles of gas immediately made their appearance on the platinum; and a strip of red litmus-paper being placed in various parts of the solution, became strongly blue in the vicinity of the platinum plate, whereas but the faintest trace of alkaline reaction was observable near the magnesium plate; magnesium was found in solution.

A similar experiment was made in a cell which was divided in the middle by means of parchment-paper. The strip of platinum in one division was connected with the strip of magnesium in the other by means of a wire, and allowed to remain for an hour, when they were removed. The liquid in the division which had contained the magnesium was slightly turbid and faintly alkaline, but did not give the slightest precipitate when poured into a solution of magnesium sulphate. The liquid in the division that had contained the platinum plate was, on the contrary, clear and strongly alkaline; and it precipitated magnesium hydrate from the neutral solution of that metal. This conclusively showed the presence of some alkaline hydrate other than magnesium hydrate, and which could not have been any thing else than potassium hydrate. The liquid in the second division was about eight times as alkaline as that in the first.

We conceive that the explanation of this reaction is that the potassium chloride in solution is itself electrolyzed. The occurrence of hydrogen against the platinum plate might be ascribed to the electrolysis of the water, the resistance of which was diminished by the dissolved salt; but this alone in no way accounts for the simultaneous formation of free alkali. If any objector should contend that the nascent hydrogen had decomposed chloride of potassium, that would still leave the removal of the acid unexplained; and as the liberated potassium would instantly decompose an equivalent of water, we should have a chemical reaction resulting in nothing but the restoration of the original state of things,

$$H+KCl+H_2O=HCl+KHO+H=KCl+H_2O+H.$$

It might be supposed that the force produced by the contact of the two metals would expend itself upon the decomposition of a small amount of potassium salt, and that then the action would cease. But experiment shows the action just described to be continuous. Several determinations were made of the alkali in the divided-cell experiment described above, at 30 minutes' and at 60 minutes' duration. The results were far from uniform; but on the average the double period showed an increase of 70 per cent. Better observations were obtained when the hydrogen evolved was taken as the measure of the action. The wire connecting the strips of magnesium and platinum was caused to pass through the whole length of a graduated tube, which was filled with the solution and inverted in it as in the annexed diagram. Hydrogen was evolved at once, and a certain volume was col-



lected in 14 minutes; a similar volume required 15 minutes, and so on, as in the subjoined Table.

	Time required.
First measure	14 minutes.
Second ,,	15 ,,
Third ,,	16 m. 50 sec.
Fourth ,,	17 ,, 40 ,,
Fifth ,,	19 ,, 20 ,,
After 20 hours	25 minutes.

After some time a white precipitate formed, the product of the action of the potassium hydrate and magnesium chloride, which increased in amount. The evolution of gas continued until the whole of the magnesium immersed had disappeared.

Sodium Chloride.

Similar experiments were made with a neutral solution of chloride of sodium containing 5 per cent. of salt. Judging by one experiment with the divided-cell arrangement, the sodium salt was decomposed somewhat more quickly than the potassium salt, as might be anticipated.

Volta, in his original pile, employed a solution of common salt as the exciting liquid. It seems to have been generally assumed, at least in late years, that it is the water alone that is decomposed; but as a matter of fact the plates become alkaline.

Ammonium Chloride.

On employing a 5-per cent. solution of ammonium chloride, free ammonia and hydrogen were obtained at the platinum plate. On causing the platinum to dip into a little mercury during the reaction the mercury increased in bulk, owing to the formation of the so-called ammonium amalgam.

Chlorides of Metals of the Alkaline Earths.

The chlorides of barium, strontium, and calcium are easily decomposed by magnesium in connexion with platinum. The hydrates pass into the liquid until it is saturated, when they precipitate. Of course hydrogen escapes at the same time from the platinum plate.

Other Combinations.

As might be expected, these actions are not confined to chlorides. The sulphates and nitrates of potassium and sodium give similar results in the magnesium connected with platinum, an alkaline hydrate always appearing against the platinum plate.

If one metal in conjunction with another more electro-negative than itself will decompose the salt of a more positive metal in aqueous solution, it may be expected, *à fortiori*, that it can decompose one of its own salts. Instances of this are not wanting.

Magnesium connected with platinum will decompose a magnesium salt, the almost insoluble hydrate of magnesium being found adhering to the negative metal. The deposition of zinc on the plates of an old-fashioned battery, when the battery is pretty well exhausted, is a well-known phenomenon. In our experiments with copper and silver in conjunction in a solution of nitrate of copper, we never succeeded in reducing the galvanic action to *nil* by our utmost efforts to exclude all oxygen: and the whole of the present inquiry originated in an experiment described by us before the Physical Society, that mercury and gold in conjunction would decompose mercuric chloride with the deposition not only of the lower chloride, but also of metallic mercury upon the gold.

[We reserve for further consideration the part played by the water in these decompositions, and the bearing of the experiments on the rival theories of voltaic action.—Nov. 26.]

II. "On the Production of Glycosuria by the Effect of Oxygenated Blood on the Liver." (Supplement to Communication presented June 17th, 1875.) By F. W. Pavy, M.D., F.R.S. Received August 12th, 1875.

In my former communication I showed that the injection of defibrinated arterial blood into the portal system occasioned the immediate production of marked glycosuria. In the present supplement to it I purpose treating of the production of glycosuria by other conditions, leading to the portal blood being surcharged with oxygen. There are also certain collateral considerations which I shall afterwards proceed to refer to.

After noticing the fact which has been mentioned, it occurred to me to try the effect of endeavouring to saturate the blood with oxygen, through the medium of respiration, to an extent beyond the capacity existing in the systemic capillaries for reducing it to its ordinary venous condition.

I first directed my efforts to attain the object desired by causing an animal to breathe oxygen instead of air.

The oxygen employed was obtained from a mixture of chlorate of potash and peroxide of manganese. I constructed a vulcanized india-rubber mouthpiece, to fit tightly over the muzzle of the dog and exclude the entrance of air. This tapered off and was connected with a piece of vulcanized tubing, which passed to a balloon containing the oxygen for use. A valvular arrangement was provided to allow only the oxygen from the balloon to enter the chest during inspiration, and to cause the expired gas to be expelled without re-entering the balloon. In this way the respiration of oxygen could be easily kept up as desired.

I found that when the gas was breathed without being purified, it acted as a powerful irritant upon the respiratory passages—exciting cough, difficulty of breathing (apparently from spasmodic contraction of the bronchial tubes), and a profuse flow of mucous secretion. The cough and excessive secretion continued for two or three days and showed that bronchitis had been set up. I at first attributed these symptoms to the presence of chlorine, for the gas possessed what appeared to be a chlorinous odour. On testing for chlorine, however, no reaction was procurable. Ozone was then looked for, and a strongly marked indication of its presence obtained. Acting upon this information, the gas was passed over peroxide of manganese in a granulated state, and was found to be completely deprived of both chlorinous odour and irritating effect upon the respiratory passages. It could now be breathed without any inconvenience whatever being noticeable. Passage through water also to some extent diminished its odour and irritant action. While, therefore, ozone acts as a powerful irritant upon the air-passages, oxygen is devoid of any irritating property.

The observations above recorded were made in 1874. In the second supplement to Watt's 'Dictionary of Chemistry' (1875), I find under the article "Ozone" that the chemical part of the question has recently formed the subject of discussion by others. Special properties are spoken of as belonging to the gas evolved from a mixture of chlorate of potash and peroxide of manganese; and while some attribute these to the presence of chlorine, Witt, in harmony with my own observations, affirms that they are due to ozone and not to chlorine.

With these preliminary remarks I come to the description of the results obtained by the respiration of oxygen in relation to the subject of this communication.

Amongst several experiments conducted upon the dog, I have met with the production of saccharine urine upon two occasions, while in the case of the others a negative result was yielded.

In one of the successful instances the animal was breathing the gas for 55 minutes. It took deep inspirations, and no irritation was excited, nor did any subsequent ill-effect arise. Indeed all that was specially noticeable, besides the deep breathing, was that at the end of the 55 minutes a state of apnœa was induced, such as is known to be occasioned by increased respiratory action. It was from this occurrence that the inhalation of oxygen was discontinued, as I felt apprehensive about the issue. In the course of a short time, however, the animal began to breathe in a natural way, and showed no signs of disturbance. The urine was examined at the commencement of the experiment, and gave no reaction of sugar. At the end of the 55 minutes there was also no decided indication of the presence of sugar; but half an hour later it contained 9·6 grains of sugar to the fluid ounce; half an hour later still, 10·48 grains; and again 40 minutes after this, 6·31 grains to the fluid ounce. At the completion of the inhalation some blood was collected from the jugular vein, and found to possess an intermediate colour between arterial and venous. On examination for sugar a strong reaction was obtainable; and through observing this, although no decided indication of the presence of sugar existed in the urine at the time, I was led to anticipate that it would be found, as proved to be the case, later on.

In the other successful experiment the inhalation was carried on in a deep and active manner for half an hour without any irritation of the air-passages being produced. When discontinued, the urine was found to contain a trace of sugar; and half an hour later sugar was present to the extent of 5·71 grains to the fluid ounce.

From observation I have been led to believe that the issue in these experiments with oxygen depends upon the manner in which the process of respiration happens to be carried on. I have frequently noticed that the movements of the chest have been performed in a signally sluggish way. In each of the experiments, on the other hand, where the production of glycosuria occurred, the breathing was carried on in a strikingly deep and active manner. It is known that the muscular operation of respiration is ordinarily conducted with an inverse degree of activity to its effect upon the blood. Through the accommodating relation existing, the more effective the oxygenation of the blood, the less actively are the movements of respiration performed; and thus, although the animal may be supplied with oxygen instead of air, it does not follow that any altered result should occur. In illustration of this I may state that upon one occasion I placed a guinea-pig in a sealed glass jar and kept a free current of purified oxygen passing through for the space of seven hours, without producing the slightest perceptible effect either at the time or afterwards upon the animal.

Some of my experiments with oxygen have been conducted upon frogs; and the plan adopted has been to place the animal in a glass jar sealed at the bottom with water, and to pass a current of the gas continuously through it for varying lengths of time. The urine is readily obtained by pressure over the bladder; and by using a small test-tube the amount collected from one animal may be quite sufficient for testing. Many of the experiments have been attended with a negative result; but in some a faint though distinctly appreciable and in others a fairly strong reaction of sugar has been obtained. Three or four hours' time has sufficed for this effect to be noticed.

Finding that I was dependent in the above mode of experimenting upon the chance manner, as it seemed, in which the process of respiration was carried on, I determined to resort to the performance of artificial respiration for the purpose of removing the uncertainty that existed. The artificial-respiration apparatus which for many years past I have been in the habit of using in my laboratory was constructed after my own design, and consists of two bellows so arranged and adapted with vulcanized tubing connected with a canula for ligaturing into the trachea, that in working the one inflates and the other exhausts the lungs. Valves are provided so as to determine this result; and with these in good order I have found, in common with what has been noticed by others, that respiration can be so effectively performed as to sufficiently surcharge the blood with oxygen to induce a state of apnœa.

Now by means of the performance of artificial respiration with the artificial-respiration apparatus referred to, I have succeeded in producing strongly saccharine urine, and this with the employment of atmospheric air. In one experiment upon a dog, where the artificial respiration was carried on for an hour, the urine, ten minutes after its cessation, gave a strong reaction of sugar. In another experiment with the artificial respiration continued an hour and twenty minutes, the urine, which was collected ten minutes after its cessation, was also strongly charged with sugar, and thirty five minutes later showed on analysis the presence of 11 grains to the fluid ounce. In each case, for the sake of precision, urine was collected and tested at the commencement of the experiment, and found to be free from sugar.

I am indebted to Dr. Lauder Brunton for directing my attention to a recorded existence of the production of glycosuria by the performance of artificial respiration. Tieffenbach (Centralblatt für die medicinischen Wissenschaften, 1869, p. 181), in referring to the production of glycosuria in curarized rabbits subjected to artificial respiration, says that he also once obtained the same result without the previous poisoning. This seems to have been a mere passing observation, while my own experiments were elicited by a train of reasoning and without the knowledge of any previously published result existing. I am not disconcerted, however, to find that I have been thus anticipated; for it is only with the question of fact that I feel concerned; and it is a satisfaction to learn that the result I have obtained is confirmed by the independent observation of another.

In the course of experimenting upon this subject, I discovered that the inhalation of the fumes of burning puff-ball (*Lycoperdon giganteum*) is rapidly productive of strongly marked glycosuria; and from certain phenomena which I observed, I at first attributed the result to an imperfect dearterialization of the blood. I noticed, for instance, when a dog was brought under the anæsthetic influence of puff-ball smoke that there was fulness and throbbing of the arteries, that the tongue became intensely red, and that the veins underneath were in a turgid state and filled with red instead of dark-coloured blood. I thought I saw in these phenomena the effects of a general vaso-motor paralysis, resulting in the blood being allowed to flow through the capillaries without becoming properly dearterialized, in the same manner as it is known to do locally after section of certain parts of the sympathetic.

Through Dr. Richardson, I have since learnt that the active agent of puff-ball smoke was some time back shown, by Thornton Herepath and Snow, to consist of carbonic oxide, a gas which reddens blood in the same manner as oxygen, but which, unlike oxygen, is not easily displaced by the agency of other gases. Now, Dr. Richardson having noticed* that the inhalation of carbonic oxide is followed by glycosuria, our respective observations coincide, and I have no reason to doubt that the circumstances are otherwise than identical; indeed a comparison of the effects of puff-ball smoke and carbonic oxide enables me to support the conclusion that the action of the former is dependent on the presence of the latter. There is the same kind of anæsthesia, the same red state of the blood contained in the venous system, and the same rapid occurrence of strongly marked glycosuria. No matter whether puff-ball smoke or artificially procured carbonic oxide may be used, within ten minutes or a quarter of an hour after the production of anæsthesia, sugar may be recognizable to a notable extent in the urine; and a little later I have upon some occasions found that my analyses have indicated the presence of as much as upwards of 30 grains to the fluid ounce.

Such is the result to which I desire to direct attention; and I will proceed to explain in what way it appears to me to stand connected with the subject under consideration.

It is seen that a gas which produces the same physical effect on the blood as oxygen likewise determines the production of glycosuria. The bright scarlet colour belonging to arterial blood is also the colour which is given to blood by the presence of carbonic oxide; and, furthermore, Dr. Gamgee has shown that the spectral properties of the compound of colouring-matter and carbonic oxide are identical with those of oxidized blood. There is this difference, however, noticeable, which seems to tell in a striking way in relation to glycosuria. The combination of colouring-matter and oxygen (oxy-hæmoglobin) is so feebly maintained that a reducing action is readily exerted by the influence of carbonic acid, and hence the facility with which oxidized is converted into deoxidized blood. In the case of carbonic oxide, however, the gas is so much more strongly held, that it is not similarly susceptible of being readily displaced by other gases. As a result of its inhalation the blood becomes charged with it, and, by virtue of the property alluded to, retains it while traversing the systemic capillaries. In consequence of this retention it is allowed to reach the liver, and there produce the effect which results in glycosuria. It is to the capacity of retention that I assume may be ascribed the speedy occurrence of glycosuria which follows its inhalation; and I think it may be surmised, seeing that oxygenated blood acts in a similar way upon the liver, that if it were not for the easy manner in which oxygen is withdrawn from the blood in its passage through the systemic capillaries, the result of its inhalation, even under the form of atmospheric air, would be the same, as far as the urine is concerned, as that of carbonic oxide. On account of the facility with which the abstraction of oxygen is effected, we obtain our escape from being glycosuric under the process of oxygen inhalation naturally carried on. The capacity of abstraction, however, is not unlimited, and, as has been shown in this communication, glycosuria may be induced by artificially surcharging the blood with inhaled oxygen.

---

* Medical Times and Gazette, March 8th, 1862.

As yet I have only assumed, without adducing any experimental evidence upon the point, that the production of glycosuria by the inhalation of carbonic oxide is due to the direct action of the blood impregnated with the gas upon the liver. It might be urged that the effect is attributable to hyperæmia of the liver, the hyperæmia being brought about either through the state of the arteries of the organ, or that of the chylo-poietic vessels in general leading to increased pressure in the portal system. An appeal to experiment has afforded a decided answer to these suggestions.

In the first place I ligatured the hepatic artery of an animal while under the effects of chloroform, and afterwards subjected it to the influence of puff-ball smoke. Before exposure to the inhalation of the puff-ball smoke, the urine was ascertained to be free from sugar. Twenty minutes after the cessation of the inhalation the urine contained 11¼ grains of sugar to the fluid ounce. The hepatic artery being tied, direct arterial hyperæmia of the liver was out of the question as a cause of the glycosuria.

In the next place I directed my attention to the question of the possibility of the effect being due to hyperæmia of the liver occurring as a result of an increased activity of the circulation through the chylo-poietic viscera, and thence an increased flow of blood through the portal vein. It was difficult certainly to realize that any thing like the hyperæmic state producible through the arterial system could be induced through the medium of the portal vein, looking at the position of the vessel with its delicate walled radicles and a capillary circulation behind. But however this might be, I determined to submit the point to experimental inquiry.

If hyperæmia of the liver from an increased afflux of portal blood constituted the cause of the glycosuria, it ought to be averted on cutting off a considerable portion of the flow through the chylo-poietic viscera.

In one experiment to accomplish this I tied the superior mesenteric artery of a dog, while the animal was under the influence of chloroform, and half an hour afterwards caused it to inhale a mixture of carbonic oxide and air, in the proportion of one part of the former to nineteen of the latter. Notwithstanding this extent of dilution it was found necessary to allow the animal to breathe pure air from time to time, to prevent a fatal result occurring. The inhalation was carried on in the manner stated for half an hour. Some urine was collected at the commencement, and found to give no reaction with the copper test, while that collected at its termination was freely charged with sugar. Urine was again collected half an hour later, and sufficient having been obtained for a quantitative analysis, sugar was found to be present to the extent of 20 grains to the fluid ounce.

In another experiment, conducted in a similar manner, I tied the cœliac axis and obtained a similar result. The urine collected a quarter of an hour after the process of inhalation was highly charged with sugar.

In each of the above experiments the perfect deligation of the arteries was verified by dissection after death; and with the amount of blood allowed to reach the portal vein so diminished, the liver must have received very much less than its ordinary supply. I consider the conclusion to be warranted that it is by virtue of its presence in the blood (and probably through the combination which possesses the same physical properties as oxy-hæmoglobin) that carbonic oxide determines the escape of sugar from the liver and thence the production of glycosuria.

The fundamental point of physiological interest brought forward in this communication is that the passage of oxygenated blood through the liver excites the transformation of its amyloid substance into sugar. Although I abstain at present from committing myself to any settled conclusion regarding the precise *modus operandi*, yet the evidence before me leads me to think that the effect is due to the action of the oxidized blood as a ferment, and not to the direct influence of oxygen; and under this view the inhalation of carbonic oxide may lead to the result observed, by the compound with hæmoglobin, which possesses corresponding physical properties to oxy-hæmoglobin, acting in a similar way. I am inclined also to think that the production of sugar is only one part of the event occurring.

It is a noteworthy fact that in the puff-ball and carbonic oxide experiments there was a strikingly rapid disappearance of amyloid substance from the liver. Under ordinary circumstances the decoction of the liver is milky, from the presence of amyloid substance, but under the conditions referred to the decoction was found nearly or quite clear. Even in the space of about an hour I have in some instances observed the decoction yielded to possess no sign of milkiness; and there was other evidence to show that the amyloid substance had disappeared.

On giving attention to the position where amyloid substance is discoverable, it appears to be especially where a limited amount of oxygen exists that it is present. There is no organ in the body supplied with venous blood like the liver, and in correspondence there is no structure which is charged to a similar extent with amyloid substance. During the first portion of intra-uterine life the liver is free from amyloid substance, while the *liquor amnii* and the fluid of the allantois contain sugar. May this not arise from the oxygenated blood of the umbilical vein causing *the amyloid substance, which might* otherwise accumulate in the liver, to pass into sugar, and thence determine a saccharine condition of these liquids? At a later period of fœtal life the liver becomes charged with amyloid substance, and sugar is no longer discoverable in the liquids named. But now the chylo-poietic viscera have attained considerable development, and would send venous blood through the portal vein to the liver. It is a specially notable fact, in relation to this point, that the liver and chylo-poietic viscera do not correspond in their state of development at different periods of fœtal life. If they did there would be no alteration in the relative supply of portal and umbilical blood to the former as time advanced. The liver, on the contrary, at an early stage is vastly out of proportion in size to even every other part of the organism. In the human fœtus, at the third or fourth week of embryonic life, it is said to constitute one half of the weight of the whole body*. At the commencement, then, the chief supply of blood to the liver must be from the umbilical vein. Subsequently, as the developmental relation becomes altered and the chylo-poietic viscera attain significant dimensions, the supply of venous blood must correspondingly increase. This may be accepted as a necessary deduction without reference to the precise anatomical disposal of the umbilical vein in relation to the liver. Under the view propounded, what before stood as an incomprehensible phenomenon becomes susceptible of rational explanation.

While the presence of amyloid substance is confined, or almost entirely confined, in the adult to the liver, it is known to have a somewhat wide extent of distribution amongst fœtal structures. Now in harmony with this the tissues of the fœtus, unlike those of the adult, are supplied with a mixture of venous and arterial blood.

The lungs and muscles are found to represent two structures besides the liver in which amyloid substance has been encountered in the adult; but examination shows that when it happens to be here physiologically recognizable it is only so to a comparatively inconsiderable extent, and this under circumstances involving a reduced supply of arterial blood. For instance, it is especially in muscles that have been kept in a state of rest, and in those of the hybernating animal during hybernation, that the substance has been noticed to be discoverable, and it has been observed to disappear under a state of activity. The lung-tissue during hybernation has been found to yield it, but fails to do so when activity is resumed.

It is an interesting and apparently a significant fact that amyloid substance is present to a notable extent in the solidified lung of pneumonia. I have myself obtained it in considerable quantity from lung-tissue in this state. Now it happens that we have here a condition, as regards the relation to blood-supply, which closely resembles that of the liver, for the tissue being solidified and impervious to air will not admit of oxygenation going on, and the blood which reaches it through the pulmonary artery, like the main supply to the liver, is of a venous character.

* Quain's 'Anatomy,' 7th ed. p. 879.

Dr. Michael Foster has shown that amyloid substance exists largely in the bodies of certain Entozoa, as, for instance, the round worm and the tapeworm. Again we have a condition which harmonizes with the other conditions under which its accumulation is observed to take place; for situated as these animals are in the intestinal canal, their position is one which is peculiarly restrictive of a supply of oxygen. My own observations have revealed its extensive existence in the mantle of the mussel, and Bernard has recognized it in the larvæ of flies. These instances, if not specially illustrative of the point under consideration, nevertheless appear to me to stand in conformity with the previous evidence.

Looking at all the considerations which have been here brought forward, I think we may generalize and say that the amyloid substance is a body which tends to accumulate in certain animal structures under the existence of a limited supply of oxygen, and that it is in consequence of the liver exceptionally receiving the supply of venous blood it does, that the special condition belonging to it is attributable. I have shown that the undue transmission of oxygenated blood to the organ at once induces an altered state, which is rendered evident by the production of glycosuria.

I consider that another link has been added to the chain of evidence against the glycogenic theory, which I have never wavered in regarding as untenable since the communication of my former researches to the Royal Society.

III. "On the Structure and Relations of the Alcyonarian *Heliopora cærulea,* with some Account of the Anatomy of a Species of *Sarcophyton;* Notes on the Structure of Species of the Genera *Millepora, Pocillopora,* and *Stylaster;* and Remarks on the Affinities of certain Palæozoic Corals." By H. N. MOSELEY, M.A. (Oxon.), Naturalist to the 'Challenger' Expedition. Communicated by Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff of H.M.S. 'Challenger.' Received September 28, 1875.

(Abstract.)

Introduction.—The author having undertaken the examination of the Deep-sea Corals dredged during the voyage of H.M.S. 'Challenger,' was led to the study of the structure of corals generally, and especially to the examination of the Milleporidæ, which seemed of peculiar interest, since they had been determined by Professor Agassiz to be Hydroids, and had been regarded by him as living representatives of the Palæozoic Rugosa. *Millepora alcicornis* was obtained and examined at Bermuda, and another species of *Millepora* at Zamboangan, Mindanas, Philippine Islands. The examination of these Millepores was found to be beset with great difficulties, and the present notes on their structure are to be regarded as only preliminary. Further investigations will be made with specimens which it is hoped will be obtained at the Sandwich Islands. At Zamboangan, *Heliopora cærulea* was obtained, and found at once to be an Alcyonarian. Its structure is described in full in the paper. Another Alcyonarian of the genus *Sarcophyton* (Lesson) was examined for purpose of comparison. It proved to present special features of interest, and a general description of its anatomy also is therefore given. Notes are further appended on the anatomy of a species of *Pocillopora* obtained at Zamboangan, and that of a Stylasteracean dredged off the Meangis Islands in 500 fathoms.

Literature of the Subject.—Few original works relating to the subjects treated of in this paper were available for reference on board the 'Challenger.' A review of what has been able to be gathered of the recent literature relating to the Tabulate and Rugose Corals and the Alcyonarians is given, and also a history of the various systematic arrangements to which the Tabulata and Rugosa have been subjected.

Professor Agassiz published his opinion as to the hydroid affinities of the Milleporidæ in 1859 ("Les Animaux des Millépores sont des Acalèphes et non des Polypes," Bibl. Univ. de Genève, Arch. des Sci., Mai 1859), and figured the animals of the *Millepora alcicornis* in his 'Contribution to the Natural History of the United States,' vol. iii. plate 15. Pourtales observed the animals in company with Agassiz. He says that one which he saw was "shorter than they are represented to be in the figure, and had five tentacular masses rather than tentacles." M.-Edwards considered Professor Agassiz's evidence as to the hydroid nature of *Millepora* insufficient, as does also Professor Allman.

Professors Claus, Pourtales, Verrill, and many other authors accept Agassiz's conclusion with regard to the Milleporidæ, but do not accept his views with regard to the Rugosa.

Professor Verrill (Silliman's American Journal, 1872, vol. iii. pp. 187, 194) found that *Pocillopora*, a genus with extremely well-marked tabulæ, was a true Hexactinian, and showed that the presence of tabulæ, the character relied on by Professor Agassiz, was of little importance. Pourtales and L. Ludwig have come to the conclusion that the tetrameral arrangement in the Rugosa is merely apparent, and that the original arrangement in the young coral was hexameral. Professor Martin Duncan arrived at similar conclusions from the examination of *Guynia annulata*. Kunth, however, still adheres to the tetrameral primary division. Lindström, the first discoverer of the opercular apparatus of certain Rugosa, compares these structures with skeletal structures of *Primnoa*. The latest paper on the classification of Corals is by M. Dollfus (Comptes Rendus de l'Acad. des Sciences, t. lxxx. no. 10, 8 Mars 1875, pp. 681–683). M. Dollfus connects together the genera *Heliolites* and *Propora* with *Heliopora* and *Seriatopora* by means of *Pocillopora*, considering all these to be Hydroids. *Favosites*, with many other genera of Palæozoic Corals, he considers to be a Bryozoon.

Methods employed.—The corals examined were hardened in alcohol or chromic acid, decalcified, and cut into fine vertical and horizontal sections. Sections of the hard parts were rubbed down in the usual manner. Portions of *Heliopora cærulea* were also examined in the fresh state.

On the Structure of Heliopora cærulea.—*Heliopora cærulea* was found growing in abundance on reefs near Zamboangan at low tide. The polyps were never seen expanded, though pieces of the coral were carefully transferred to a glass vessel without being removed from the water. The living coral is perforated in all directions by a parasitic Annelid (*Leucodora*). The corallum of *Heliopora* is remarkable for the tubular character of its cœnenchym, which consists of a series of tubes arranged side by side at right angles to the surface of the coral, open above but closed below by successive transverse partitions or "tabulæ." The calicles are tubes essentially similar to the tubes of the cœnenchym, but larger. They are said by M.-Edwards to have twelve septa appearing as plications of the wall of their cavities. The number is, however, very variable. The tabulæ of the calicle are exactly similar in structure to those of the cœnenchym. The hard tissue is composed of doubly refracting calcareous matter, which has a half-crystalline, half-fibrous structure. It is disposed in a series of systems vertically to the surface of the corallum, the axes of which systems lie in the interspaces between the cœnenchymal tubes. In each system the fibres of hard tissue are disposed radially around the central vertical axes, and at the same time with an upward inclination at an equal angle all around.

The colony of *Heliopora* is developed entirely by budding. In a growing point of the corallum the cœnenchymal tubes are widely open and polygonal in outline. New calicles are formed by the junction of a number of tubes around a central tube or tubes arrested in growth which form a base. The outer walls only of the surrounding tubes continue to grow and form the lateral wall of the calicle. The newly formed calicle thus has tubular prolongations at its base, and the so-called septa are, in the main, due to the circumstance that the wall is composed of a series of fused curved outer walls of tubes. The calcareous matter is deposited in a finely fibrous calciferous tissue, connected apparently with the formation of which is a layer of connective tissue which everywhere covers the hard parts.

There is no trace of the corallum of *Heliopora* being composed of fused spicules as in the case of *Corallium* and *Tubipora**.

---

* The fact that the corallum is so formed in *Tubipora* seems to have been hitherto unknown (Claus, 'Grundzüge der Zoologie,' 3^{e} Aufl. p. 204). It is plainly shown at the mouth of any growing tube in spirit specimens. Professor Wyville Thomson drew my attention to the fact, an account of which he thinks has been published by Professor Perceval Wright in the 'Annals and Magazine of Natural History.'

The deep blue colouring of the corallum of *Heliopora* is due to an amorphous colouring-matter insoluble in strong hydrochloric acid, but soluble in acidified alcohol. It forms an intensely blue solution of a sulphate of copper colour, which transmits the blue and part of the green only of the spectrum.

In the soft tissues of *Heliopora* an ectoderm, entoderm, and mesoderm are to be distinguished. The ectoderm is composed of club-shaped cells; it has the usual disposition. Small oval nematocysts are present in it and in the upper part of the mesodermic layer beneath. The mesoderm consists of three histological elements, homogeneous connective tissue, layers of connective-tissue cells, and finely fibrous calciferous tissue. Prolongations of the two former form sacs lining the cœnenchymal tubes and calicles. The sacs are further lined by the entoderm, which consists of spherical cells containing yellow pigment, as in other Alcyonarians. Only a surface-layer in *Heliopora* is living. Hardly any soft tissue is to be found in the tubes beneath the last-formed tabula. The sacs lining the tubes do not communicate anywhere directly with the exterior, but are connected with one another above, and with the calicular cavities, by wide transverse canals. The superficial tissues are permeated by smaller canals. The polyps of *Heliopora* have eight mesenteries and eight lobed tentacles. In the contracted state of the polyp the tentacles are completely introverted, and rest in the inter-mesenterial spaces. The stomach is like that of any other Alcyonarian. Retractor muscles are present, which are disposed with regard to the mesenterial plates as in Pennatulids, showing a "Dorsalfach" and "Ventralfach." No definite protractor muscles were observed to be present. No regular arrangement of the eight mesenteries with regard to the twelve so-called septa could be found. Eight mesenterial filaments are present, two of which appear to be longer than the others. In three individuals only of the single colony examined were ova found—in one four ova, in the others only one. The ova are attached to the mesenteries. The four ova were attached to four separate mesenteries. No male elements were found. The colonies are probably unisexual. The arrangement of the polyps in the colony is somewhat irregular; but the "Dorsalfach" seems always to be uppermost in the vertical plates of which the coral consists, the polyps being thus placed back to back.

On the Structure of Sarcophyton, sp.—An Alcyonarian was obtained at the Admiralty Islands which agrees in every respect with Lesson's genus *Sarcophyton* (M.-Edwards, Hist. Nat. des Corall. t. i. p. 22). A genus called *Sarcophyton* is, however, cited by Claus as having been formed by Sars. The Alcyonarian is mushroom-shaped. Two kinds of individuals, zooids and polyps, compose the colony; the stem is composed of large tubes ("sinus"), the prolongations of polyp-cavities. The polyps offer no marked peculiarities; their retractor and protractor muscles are arranged as in Pennatulids with regard to the mesenteries. They have two mesenterial filaments longer than the rest. The zooids have eight short mesenteries, four of which, the "dorsal" and "ventral," are deeper than the rest. They have two mesenterial filaments, the dorsal only. They have no tubercles and no generative organs. They have a simple globular stomach, communicating by a short tube with the exterior, and lined with long cilia. A sarcosome of transparent homogeneous connective-tissue, containing small ramified nucleate corpuscles, connects the polyp- and zooid-cavities; these cavities are connected by vertical and horizontal systems of canals. The vertical canals are continuous with the bottoms of the zooid-cavities; they form networks of canals in the sarcosome. The sarcosome contains elongate tuberculate spicules of the usual form, which are largest and most thickly set in the stem of the *Sarcophyton*. Smaller spicules are present in the tentacles of the polyps. The spicules show a special sheath of transparent tissue, in which structure was not seen. The "Dorsalfächer" of the polyps and zooids have a general direction towards the central axis of the stem and centre of the pileus; but both polyps and zooids are often more or less twisted on their axes.

On the Structure of Millepora.—The examination of *Millepora* is beset with serious difficulties; the present notes are merely preliminary. The calcareous cœnenchymal tissue of *Millepora* differs extremely from that of *Heliopora* in being reticulate, not tubular: in histological structure it is similar to *Heliopora*. The coral has only a thin superficial layer of soft living tissue, composed of a network of canals filled with cells resembling those of the canals of Alcyonarians, and covered externally with nematocysts. Two kinds of nematocysts, small and large, are present: the small ones are confined to the tentacles. Two kinds of polyps are present, large and small. Tentacles are present in both kinds; they appear to be four in number and compound. They are simply retracted by means of muscular fibres, which are arranged round the base of the cylindrical stomach radially, but, as far as has yet been seen, without any disposition in definite groups. No mesenteries have been seen.

On the Structure of Pocillopora (P. acuta).—The corallum is very dense and composed of definite prisms of calcareous matter, which show a transverse banding, somewhat like that of striped muscular fibres. The polyps have twelve tentacles, six large and six small, and twelve mesenteries with long mesenterial filaments coiled up. A very thin layer of living tissue covers the corallum; it is devoid of canals.

On the Structure of Stylaster.—A *Stylaster* dredged in 500 fathoms was found to have the tentacles disposed *between* the calcareous septa, as was shown to be the case in *Allopora oculina* by Sars (Forh. Selsk. Chr. 1872, p. 115). The septa are twenty-two in number, and the tentacles also twenty-two. The stomach has a conical projecting mouth or proboscis, as seen by Sars in *Allopora oculina*. It has apparently no inferior outlet. There are no well-defined mesenteries, and no mesenterial filaments. A very open network of soft tissue surrounds the stomach and tube leading to it from the circle of the tentacles. Suspended in this reticulate tissue are the testes, large sacs filled with spermatic cells disposed sometimes in one, sometimes in two vertical rows; they occupy the interior of the ampullæ. These corals are diœcious. *Cryptohelia* resembles *Stylaster* most closely in structure, and is also diœcious.

Vegetable Parasites.—The corallum of both *Millepora* and *Pocillopora* is permeated by fine ramified canals, formed by parasitic vegetable organisms of the same nature as those described by Dr. Carpenter and Professor Kölliker as occurring in the shells of mollusks &c. The organisms were found in abundant fructification; they are green, but otherwise appear to be fungi, as are the parasites of shells &c. Similar parasites are to be found in various coralla from widely distant parts of the world.

CONCLUSIONS.

Heliopora is most undoubtedly an Alcyonarian. The number of its mesenteries, and the distribution with regard to them of the retractor muscles, the form and number of its tentacles, are decisive evidence in the matter; and this evidence is borne out by almost every item of histological structure. In the peculiar manner in which the retraction of the tentacles takes place, viz. by introversion, *Heliopora* seems to differ from all other Alcyonarians except *Corallium*[*]. From both *Corallium* and *Tubipora*, *Heliopora* differs in that the hard tissue of its corallum shows no signs of being composed of fused spicules, but in its histological structure most closely resembles Zoantharian Corals. With the Milleporidæ and with the Pocilloporidæ and Seriatoporidæ *Heliopora* is allied solely on account of its possession of tabulæ. Now that an Alcyonarian is added to the list of various Anthozoa possessing these peculiar structures, their presence becomes of less classifactory importance even than Professor Verrill proved it to be. There can hardly be a doubt that *Seriatopora* will prove to be, like *Pocillopora*, a Zoantharian; and *Millepora* is certainly very different in structure from *Heliopora*. *Heliopora* thus stands quite alone amongst modern forms; and in the peculiar structure of its cellular cœnenchym it is so remarkable that it is unlikely that on examination of the soft parts of other corals, at present known from their coralla only, any near relatives of it will be discovered. Amongst extinct forms, however, *Heliopora* has several close allies, and the genus itself existed in the Cretaceous period. The genus *Polytremacis* differs apparently only in the more perfect development of the so-called septa, which reach to the centres of the tabulæ. The genus occurs in the Chalk, Greensand, and in Eocene formations. *Heliopora* has, further, a very closely allied palæozoic representative in *Heliolites*, in which the cœnenchymal tubes are provided with very closely placed tabulæ.

---

[*] I have found no information on this point in any of the text-books; but in Schmarda's 'Zoologie' there is a figure of *Corallium*, copied from Lacaze-Duthiers's 'Hist. Nat. du Corail,' in which the tentacles are drawn introverted as they are in *Heliopora*.

The three genera *Heliopora*, *Polytremacis*, and *Heliolites* differ from one another to so slight a degree that they are placed under the one genus *Heliopora* by Quenstedt. To include these three genera, a new family of Alcyonarians must be formed, for which the term Helioporidæ appears most suitable, which family may from the recent species be thus characterized:—

Family HELIOPORIDÆ.

A compact corallum present, composed of a fibro-crystalline calcareous tissue as in Madreporaria. Corallum consisting of an abundant tubular cœnenchym, and with calicles having an irregular number of lateral ridges resembling septa. Calicles and cœnenchymal tubes closed below by a succession of transverse partitions. Polyps completely retractile, with tentacles when in retraction introverted. Mouths of the sacs lining the cœnenchymal tubes closed with a layer of soft tissue, but communicating with one another and with the calicular cavities by a system of transverse canals.

The structure of the cœnenchym of the Helioporidæ is entirely unique amongst Anthozoa; no other form has a cœnenchym composed thus of a series of long tubes packed side by side, and lying parallel to the calicular tubes and at right angles to the surface. It is to be remarked that the tubes are like the calicles in being open above, that they have walls composed in exactly the same manner as those of the calicles, and that they are closed below at intervals in the same way by exactly similar tabulæ. Further, the soft tissues lining the cavities of the cœnenchymal tubes are identical in structure with those lining the calicular cavities, and the same transverse system of canals connects the summits of the tubes with one another and with the summits of the calicular cavities.

It seems by no means improbable that the cœnenchym here is composed of the tubes of absorbed polyps or zooids which have lost the rudimentary organs, which they still possess in such a form as *Sarcophyton*, and have become mere tubular cavities, whose openings to the exterior even have been obliterated; it seems impossible otherwise to account for the presence of the successions of tabulæ in the cœnenchymal tubes. The foregoing considerations are suggested by the circumstance that a series of fossil corals, grouped by M.-Edwards under the Tabulata, appear most probably to have been Alcyonarians as well as *Heliopora*.

The genus *Chætetes* was considered by Keyserling to have belonged to the Alcyonarians, because of the absence of septa in it, and the mode in which its polyps are grouped; but Milne-Edwards retains it amongst the Zoantharians, because of its close resemblance to the Favositidæ, in which the presence of septa is regarded as conclusive in deciding against Alcyonarian affinity. The presence of calcareous septa, however, must now be considered a character of less importance than it formerly was. As is seen in the case of *Heliopora* pseudo-septa may exist, which do not necessarily correspond in any way, in disposition or number, with the membranous mesenteries. In *Stylaster* and *Cryptohelia*, the calcareous septa are obviously formed as infoldings of the margin of the calicles. Here the septa are between, instead of opposite to the tentacles; and membranous mesenteries appear to be absent, or at all events rudimentary only. In the Favositidæ the septa seem to have been no more perfect than they are in *Heliopora*, and to have been most variable in number, but often twelve, as also in *Heliopora*. M.-Edwards describes from 10 to 12 septa in *Favosites gothlandica*. In *Michelinia favosa* 30 to 40 subequal septal striæ are to be made out at the upper margin of the wall of the calicle. I cannot refer to specimens; but it seems not unlikely that the septa in the Favositidæ were pseudo-septa as in *Heliopora*, and that these coralla were formed by Alcyonarians, the perforations in the walls having transmitted transverse canals like those of *Heliopora* and *Sarcophyton*, and the coralla being free of tabular cœnenchym, because none of the polyps were aborted as in *Heliopora*. Some Favositidæ seem to have formed a compound colony, consisting of polyps and zooids, as *Favosites Forbesii*, where a few large cells are seen set amongst numerous surrounding small ones. *Heliolites* seems to a certain extent to form a transition stage between a condition such as that in *Favosites Forbesii* and the condition in *Heliopora*; for in *Heliolites*, the more ancient form, the cœnenchymal tubes are regularly hexagonal, and apparently much more nearly equal in breadth to the calicles than in *Heliopora*. In the growing points of *Heliopora* the hard parts are made up of a series of open, often hexagonal tubes, and resemble *Favosites* in their surface aspect. In *Heliopora* the transverse canals pass over notches in the summits of the walls of the cœnenchymal tubes and calicles, in order to place these cavities in communication with one another. In *Favosites* the calcareous tissue surrounded the transverse canals, and the perforations in the walls of the calicles were thus produced.

If *Favosites* was an Alcyonarian, *Chætetes* was of course also of that group. The genus *Alveolites* amongst the Favositidæ is peculiar for the possession of three tooth-like prominences as the only representatives of septa. One tooth, well developed, is situate inside the calicle; on that side of each calicle which lies externally in the colony, and opposed to this on the tip of the calicle next the interior of the colony, are a pair of rudimentary teeth. This arrangement reminds us at once of the distinction of dorsal and ventral mesenterial interspaces in Alcyonarians, and the direction of all the "Dorsalfächer" in *Sarcophyton* and *Heliopora* towards the central axis of the colony. In *Alveolites* the two teeth seem to correspond to the "Dorsalfach," and the single one to the "Ventralfach," the two teeth having occupied the space devoid of retractor muscles. Kölliker describes a series of teeth as existing at the margin of the calicle in *Renilla*, which follow a constant law in their relation to the septa. When only one tooth is present it is opposite the "Dorsalfach;" when three, one is opposite the "Dorsalfach," and the two others opposite the lateral "Ventralfach." In *Alveolites* the one tooth is ventral instead of dorsal. In *Syringopora* the septa seem to be very much of the same nature as in *Heliopora*; and in *Heliopora*, as already described, the tabulæ are not merely transverse floors, but the bottoms of cups of hard tissue fitted inside the older tubes and calicles. In *Syringopora* this condition of the tabulæ is much more marked, and the corallum appears as if formed of a series of calicles fitted one within another.

A difficulty appears to arise from the peculiar mode of the development of the calicles by budding in *Heliopora*, the foldings of the walls of the calicles being due, to a considerable extent at least, to the formation of these walls from a circle of cœnenchymal tubes. The septa are, however, not entirely formed in this way. It would of course be of great interest to see whether the primitive calicle, in the developing *Heliopora* colony, forms calcareous septa.

Heliopora having so commonly twelve septa, and in conjunction with these eight mesenteries, it was at first thought that here some key would be found to the elucidation of the question of the relations of the tetrameral corals to the Hexactinians; but no definite arrangement of the eight mesenteries to the twelve septa could be discovered. Ludwig and Pourtales have concluded that the tetrameral condition in the Rugosa is the result of a modification of an originally hexameral arrangement—that the Rugosa are, in fact, modifications of the Hexactinian type. Kunth, however, using similar methods, has come to an opposite conclusion. Now that it is known that an Alcyonarian exists which constructs a solid calcareous corallum, in histological structure scarcely, if at all, to be distinguished from that of many Madreporaria, and that this Alcyonarian also possesses marked calcareous septa, which septa show, notwithstanding the octameral arrangement of the mesenteries, a hexameral disposition in being often twelve in number, it seems that the question of the affinities of the Rugosa may fairly be reopened. The presence of well-marked calcareous septa in *Cryptohelia* and other Stylasteridæ (which septa are equal to the tentacles in number, but nevertheless to be regarded, like those of *Heliopora*, as pseudo-septa) is significant. The marked tetrameral arrangement of the septa in Rugosa, and the presence in many forms of tabulæ, are certainly characters not opposed to the alliance of these corals with the Alcyonarians; and the fact that paired series of opercula occur in certain Rugosa, which are compared by Lindström, their discoverer, to the skeletal structures of certain *Primnoæ*, seems to be evidence in favour of such an alliance of the very strongest kind. In no Madreporaria do paired hard structures, at all resembling those of *Primnoæ* or of *Goniophyllum pyramidale*, occur. The opercular structures in the coralla of *Cryptohelia* and *Lepidopora* can scarcely be regarded as comparable with the opercula of Rugosa. The structures are merely folds of the lip of the calicle, and are continuous with it and immovable, not movable separate articulate structures. Many

Rugosa show an arrangement which may well be compared to the distinction of dorsal and ventral regions in Alcyonaria. The most important distinctive character of the Rugosa appears to be the occurrence in them, alone of all Anthozoa, of intracalicinal gemmation *.

With regard to *Sarcophyton*, the fact that compound colonies composed of multitudes of zooids, combined with a lesser number of sexual polyps, occur amongst the Alcyonidæ, as well as amongst the Pennatulidæ, in which they are so well known from Kölliker's great work, appears to be new to science. That in such colonies and in *Heliopora* the "Dorsalfacher" are all turned towards the axis of the colony and directed upwards is also a new fact. The zooids in their structure seem to conform very closely to those of Pennatulids (*Sarcophyllum*, e. g.); but to the list of distinctive differences between the zooids and polyps of Pennatulids given by Kölliker, viz. the absence in the zooids of tentacles, the presence of two mesenterial filaments (the dorsal ones), the absence of generative organs, and the shortening of the hypogastric region to such an extent that it fuses with the anastomosing canal-system—to these marks of distinction must be added, in the case of the zooids of *Sarcophyton*, the fact that four of the mesenteries, the dorsal and ventral pairs, are deeper than the others.

It seems extremely difficult to reconcile the extraordinary succession of the mesenteries in the development of the Zoantharians, discovered by Lacaze-Duthiers, with the facts presented by Alcyonarians. Did the development of the eight mesenteries of Alcyonaria correspond with that of the first eight mesenteries formed in Actiniadæ, the first mesenteries formed would be either the lateral dorsal or lateral ventral; but these are those which are most rudimentary in the zooids of *Sarcophyton*. Moreover the mesenterial filaments of the two lateral pairs of septa are in the development of Actiniadæ the first to appear, and not the dorsal, which are longest in the Alcyonarian polyps and most persistent in the zooids. Apparently, however, development in Alcyonarians follows a different course.

In *Halysceptrum*, the development of which has been examined by Kölliker, the eight mesenteries appear from the very first. In *Kalliphobe* (Busch), one of the *Edwardsiæ*, according to Metschnikoff, the larva has, in its earliest stage, eight tentacles and two mesenterial filaments.

The peculiarities presented by the Stylasteridæ have struck many observers. M.-Edwards and Haime placed these corals (Stylasteracea) under the Oculinidæ. Gray, however, established a family (Stylasteridæ) for the genus *Stylaster* alone. Pourtales, who in his 'Deep-Sea Corals' dwells upon the many peculiarities of the corallum of this family, places under it the genera *Allopora*, *Stylaster*, *Distichopora*, *Cryptohelia* †, *Lepi-*

---

* An examination of the Cornulariadæ, the only recent solitary Alcyonarians, might very possibly throw light on the question of the affinities of the Rugosa.

† Pourtales has remarked that the genus *Endohelia* of M.-Edwards and Haime

dopora, and *Errina*. The peculiarities in the structure of the soft parts, and the relations of the tentacles to the septa, described in this paper as occurring in a *Stylaster* and a *Cryptohelia*, and the similar facts observed by Sars in the genus *Allopora*, strengthen the facts brought forward by Pourtales, with regard to the coralla, in a very potent manner. I hope to make a close study of the structure of *Stylaster*. The apparent absence of mesenteries is most remarkable, and a similar condition appears to occur also in *Millepora*. The number of tentacles and septa in the Stylasteridæ seems hardly to follow the usual hexameral law. In the species of *Stylaster* examined by me there are invariably twenty-two septa and twenty-two tentacles. In *Stylaster erubescens*, Pourtales describes the septa as being in number from nine to twelve, most frequently eleven. In *Allopora miniata* the septa are from seven to ten, generally eight. *Cryptohelia* has commonly sixteen.

With regard to the affinities of the Milleporidæ, no certain conclusion can be arrived at from the few facts yet ascertained. I hope to obtain specimens at Hawaii in sexually mature condition.

H.M.S. 'Challenger,' North Pacific.
21st July, 1875.

POSTSCRIPT.

Since the above was written I have been able to refer at Honolulu to Prof. Lacaze-Duthiers's 'Histoire Naturelle du Corail.' I therefore add a few notes.

In *Corallium* the contracted polyp presents externally at the surface eight lobes coloured red. When the polyp is expanded, these lobes form a coloured cup with eight dentations at its margin, which surrounds the lower part of the expanded colourless polyp (see pl. 2 of Prof. Lacaze-Duthiers's work). The eight lobes described as closing the mouth of the calicle in the contracted polyp of *Heliopora* probably occupy a similar position, and have a similar appearance in the expanded condition of the polyp.

In *Corallium* the pinnæ or barbules of the tentacles are all severally introverted (*l. c.* p. 57), as well as the tentacles themselves. In *Heliopora* this appears not to be the case. In the hard tissue of *Corallium* boring vegetable parasites occur, as observed in *Millepora* and *Pocillopora*.

I have further been able to refer to Dana's great work on Corals in the splendid collection of scientific works in the Government Library at Honolulu, and to other works relating to *Heliopora*.

Dana states (U.S. Expl. Exped. vol. vii. Zoophytes, J. D. Dana, Philad. 1846, p. 539) that the blue colour of *Heliopora* is of animal origin and

---

appears indistinguishable from the genus *Cryptohelia* of the same authors. *Endohelia* is founded on a Japanese species. The 'Challenger' dredged a coral certainly not distinguishable from *Cryptohelia* generically off the coast of Japan.

is lost on immersion of the coral in nitric acid. The colouring-matter was not analyzed by Mr. Gilliman.

In the Atlas of the 'Voyage de l'Astrolabe,' Zoophytes, pl. 20. figs. 12, 13, 14, the expanded polyps of *Heliopora cærulea* are figured by MM. Hombron and Jacquinot. In fig. 14 sixteen very short, simple, conical tentacles are shown, in fig. 13 only fifteen tentacles. The figures are evidently very erroneous. The corresponding description I have been unable to refer to, the volume containing it being wanting in the Hawaiian Government copy.

In the Zoology of the 'Voyage de l'Uranie,' Quoy and Gaimard, Paris, 1824, p. 656, is a description of the polyps of *Heliopora* (*Pocillopora*) *cærulea.*

The expanded polyps have radiated tentacles, and are said to entirely hide the corallum when they are in an expanded condition. Experiments proved that communication between the animals is somewhat imperfect, since a stimulus applied to any part of the colony caused only the polyps in that immediate neighbourhood to retract themselves.

In the plates of the 'Voyage de l'Uranie,' pl. 96. figs. 5, 6, 7, *Heliopora* is figured, showing in fig. 5 the appearance of the coral in the fresh state, but without any representation of the polyps.

November 30, 1875.

ANNIVERSARY MEETING.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

Dr. W. Pole, for the Auditors of the Treasurer's Accounts on the part of the Society, reported that the total receipts during the past year, including a balance of £274 11*s*. 10*d*. carried from the preceding year, amount to £4915 19*s*. 11*d*.; and that the total expenditure in the same period amounts to £4672 9*s*. 11*d*., leaving a balance at the Bankers' of £220 13*s*. 8*d*., and £24 6*s*. 4*d*. in the hands of the Treasurer.

The thanks of the Society were voted to the Treasurer and Auditors.

The Secretary read the following Lists:—

Fellows deceased since the last Anniversary.

On the Home List.

Lieut.-Col. North Ludlow Beamish, K.H. (in 1872).
William John Blake, M.A.
General John Briggs.
Rev. Thomas Burnet, D.D.
Benjamin Bond Cabbell, M.A.
Richard Christopher Carrington, F.R.A.S.
Rev. Charles Boileau Elliott, M.A.
John Edward Gray, Ph.D.
Daniel Hanbury, F.L.S.
John Hardwick, D.C.L.
William Jory Henwood, F.G.S.
The Very Rev. Walter Farquhar Hook, D.D.
Rev. John Hoppus, LL.D.
Capt. Joseph Henry Kay, R.N.
Prof. Thomas Hewitt Key, M.A.
Francis Kiernan, F.R.C.S.
Sir Charles Locock, Bart., M.D.
Sir William Edmond Logan, LL.D.
Sir Charles Lyell, Bart., LL.D.
Rear-Admiral Sherard Osborn, C.B.
Jesse Watts Russell, D.C.L.
The Right Hon. Sir Edward Ryan, M.A.
William Sanders, F.G.S.
Rev. Canon William Selwyn, D.D.
Charles Blacker Vignoles, V.-P. Inst. C.E.
Thomas Webster, M.A.
Sir Charles Wheatstone, Knt., D.C.L.
Sir John Gardner Wilkinson, Knt., D.C.L.
Rev. Robert Willis, M.A.
Colonel Philip Yorke.

On the Foreign List.

Friedrich Wilhelm August Argelander.
Jean Baptiste J. D'Omalius d'Halloy.
Samuel Heinrich Schwabe.

Fellows elected since the last Anniversary.

On the Home List.

William Archer, M.R.I.A.
James Risdon Bennett, M.D.
Dietrich Brandis, Ph.D., F.L.S.
James Caird, C.B.
Henry Howard Molyneux Herbert, Earl of Carnarvon.
Prof. John Casey, LL.D.
Right Hon. Sir James William Colvile, Knt.
August Dupré, Ph.D., F.C.S.
Right Hon. William Edward Forster.
James Geikie, F.R.S.E.
James Whitbread Lee Glaisher, M.A.
Right Hon. Russell Gurney, Q.C.
J. Baboneau Nickterlien Hennessey, F.R.A.S.
Emanuel Klein, M.D.
E. Ray Lankester, M.A.
George Strong Nares, Capt. R.N.
Right Hon. Sir Stafford Henry Northcote, C.B.
Robert Stirling Newall, F.R.A.S.
William Chandler Roberts, F.C.S.
Major-General H. Y. D. Scott, R.E., C.B.

On the Foreign List.

Pierre J. van Beneden.
Joseph Louis François Bertrand.
Alfred Louis Olivier Des Cloizeaux.
Hippolyte Louis Fizeau.
Elias Magnus Fries.
Jules Janssen.
August Kekulé.
Gustav Robert Kirchhoff.
Carl Ludwig.

The President then addressed the Society as follows :—

GENTLEMEN,

THE year that has elapsed since our last Anniversary has been a memorable one under both pleasurable and painful aspects: on the one hand we have lost by death a greater number of and more illustrious Fellows than during any year within our recollection; on the other, our sphere of activity has been enlarged in various directions, so that, if it has been the saddest, it has been also the most busy year known to any of us.

Our losses, numbering no less than thirty-two, include two most eminent geologists, Sir Charles Lyell and Sir William Logan; two physicists in the foremost rank, Sir Charles Wheatstone and the Rev. Prof. Willis; the most learned pharmacist of his day, Mr. D. Hanbury; a zoologist of great repute and long career of astonishing activity, Dr. J. E. Gray; together with three men of great eminence in letters, and one for public services, The Right Honourable Sir Edward Ryan, The Very Reverend Dean Hook, Sir John Gardner Wilkinson, and Admiral Sherard Osborn. On the foreign list I have to record the names of two great astronomers in Friedrich W. A. Argelander, of Bonn, and Heinrich Schwabe, of Dessau, and a distinguished geologist, Jean Baptiste J. D'Omalius d'Halloy, of Brussels.

For evidences of our activity, I must refer to our publications and to the number of papers read at our Meetings; to the labours of the Committees that have been employed on duties in connexion with Expeditions, all more or less under the authority of Her Majesty's Government, as the "Polar," the "Total Solar Eclipse," and the "Transit-of-Venus" Expeditions, or in duties such as appertain more directly to the business of the Society.

On the recommendation of the Soirée Committee, in addition to the annual Conversazione, two very successful Evening Receptions of a less public character, to which the invitations were of necessity very limited, were held in our Library. Their repetition during the present session will no doubt be considered by the Committee, and if thought desirable, will be recommended to the Council, who will, I am sure, heartily cooperate with the Officers in any plan for promoting scientific reunions appreciated by the Fellows.

The Library Committee has had under consideration the mode of publication of our 'Transactions,' so as to afford to specialists and the public the opportunity of obtaining copies of separate papers at the lowest cost. The result is a recommendation, adopted by the Council, that a certain number of copies of every paper—the paging as in the Transactions being retained—shall be placed with the publishers, Messrs. Trübner and Co., for separate sale, without prejudice to the usual grant of free copies to the authors. It has also been determined that the Parts of the Philosophical Transactions shall be published, with cut edges, in cloth boards, at no additional cost to the Fellows.

The Catalogue of Scientific Papers for the decade 1864 to 1873 inclusive is so near completion, that it will be ready for the printer in a few months. It comprises at present ninety-five thousand titles, and will probably occupy two volumes, of the same dimensions as those already published. As you are aware, the whole expense of preparing the Catalogue was borne by the Society, and the printing of the six volumes was undertaken by the Treasury, at the instance of Lord Palmerston and Mr. Gladstone. An application will be made to Her Majesty's Government for the means of printing the decade now all but ready; it will cost proportionally less than the former series, and I cannot but believe that the means for so important an undertaking will, as before, be granted.

The second volume of Dr. Klein's work 'On the Anatomy of the Lymphatic System' has been published, and one hundred copies have been distributed by the Council. The cost of the illustrations of this and the former volume was defrayed out of the fund of the Government Grant.

You will observe in the Treasurer's printed balance-sheet that a larger sum than heretofore is now paid for insurance against fire. In entering into occupation of our new house, your Council resolved on fully protecting the Society (so far as is possible by insurance), and an efficient valuation of our property was made, the Library, containing more than thirty-eight thousand books, being taken at £18,000, and the Portraits and Busts at £4000.

Notice has been received from the Society's Solicitors that the portion of the Dircks' Estate to which we are entitled—has at last been set free, and that the amount (about £1000) will shortly be paid to our Treasurer.

The Handley Bequest is, I regret to say, still *sub judice* in Chancery.

A portion of the Society's land at Acton, comprising 145 square yards, required for the site of a Parsonage, has been sold to the Ecclesiastical Commissioners for a sum of £350.

You have learned, with mingled feelings of regret and of satisfaction, that our late most eminent Fellow, Sir Charles Wheatstone, has, with that devotion to science and to the Society that distinguished his long and intimate connexion with us, bequeathed a sum of £500 in augmentation of the Donation Fund.

The Election Statutes.—At our Anniversary of last year the attention of the Meeting was called by Dr. Williams to the present limitation in the election of ordinary Fellows; and though no action was taken at the time, the subject appeared to me to be one so deeply affecting the interests of the Society, that I did not hesitate to take the earliest opportunity of submitting it to the deliberations of the Council. This resulted in the appointment of a Committee to consider the whole question of the "Election Statutes."

In the mean time Dr. Williams addressed to myself a letter embodying his views on the subject, which, having been printed and circulated throughout the Society, requires my acknowledgment from this Chair, and is entitled to the most full and careful consideration. Therefore, while disclaiming the slightest intention to criticize the letter in a hostile spirit, and while fully appreciating the interest in the Society's welfare which caused Dr. Williams to raise the question of a revision of the Election Statutes, I feel bound to remark that I cannot think he had considered the question in all its aspects, or made allowance for the effects of that inability on his part, which he so candidly admits and regrets, to take, during forty years' Fellowship, any active part in the proceedings of the Society.

Had it been otherwise, he would surely not, without some reservation, have instanced the reduction in the number of Fellows since the present rules have been in force as a loss to the Society which had not been anticipated; he would have been aware that the rules now in operation had been approved by the Society individually and collectively, and with ample deliberation, before their embodiment in the Statutes. He would also have known that it was with the full knowledge and intention that such a reduction would and should result from this step that the rules were adopted, and that the rate and amount of reduction formed the subject of investigation and report by an eminent Fellow and Statistician, Mr. Galloway; and lastly, that the rate of reduction, as then anticipated and taken into account, has been slower than was calculated, and that our number for some years to come will still be in excess of that which in 1847 was, and I have reason to believe still is, thought large enough by the great majority of our Fellows.

Again, it is undoubtedly under a misapprehension that it is asserted that the general result of the present limitation in the number annually elected has been the "rejection of two thirds or more of the candidates." The fact is that (putting aside the application of the term "rejection" to that which, in the majority of cases, is merely "postponement") two thirds of all whose names have been suspended have actually been elected, not rejected; and the average duration of suspension of the elected candidates has been under two years. Furthermore, from the one third who have not been elected are to be excluded the deaths, the withdrawals, and those whose proposers have omitted to suspend their names a second year. Subtracting these, the "caput mortuum" is not only a very small one, but is one which the Society would not, in my judgment, wish to have taken into Fellowship.

It has been observed, and justly, "that the Fellows know little of the composition of the Scientific Committees," and that, "if they are to judge by the composition of the Council, the choice seems limited." With regard to the first observation I need hardly remind you that the Council Minutes, in which the nomination and duties of the Committees and the names of their members are detailed, lie open daily to the inspection of the Fellows; and with regard to the second, that Dr. Williams himself would, were he to inquire, be surprised to know how few resident Fellows there are who, being competent, are both willing and able to serve on the Council. I have had some experience in public business, and can confidently affirm that, for number and duration of sittings, amount of work brought before them, and amount of thought devoted to that work, I know no labours of the kind more various, onerous, and engrossing than those of the Council and Committees of the Royal Society. I have had at various times during the last quarter of a century much experience of these Councils, and never knew a year in which, of the ten Members of the Council who, in accordance with the Charter, have to be replaced, there were not some who had attended a very limited number only of its meetings; and as by a Minute of Council five names of Fellows who have never previously served must annually enter into the composition of the new Council, and as these five are, for the most part, chosen from comparatively new Fellows, it cannot be said that sufficient fresh blood is not annually incorporated. But for the punctual attendance of the Members of Council, the Officers could not carry on the Society's business. These latter meet punctually at 1 P.M. on every Council-day (sometimes at intervals of a week), and sit continuously until the Council breaks up, which is rarely before six.

And if it is difficult to obtain Members to sit in the Council, it is in my experience far more difficult to secure attendance at the Committees, which in many instances include no Councillor among their number. To go into the reason for this is here not necessary; it is sufficient to say, that additions to the number of Fellows annually elected would not overcome the difficulty now in question.

I have but one remark to make further on this subject. It is asked, "Are we not straitened by our restrictive measures?" and it is implied that we are unable to meet the cost of illustrations to papers communicated by Fellows. The following statements, given on the Auditors' authority in my last year's Address, have escaped the attention of the writer of the letter, viz. that "there was no cause for apprehension in respect of the Society's funds or income," and that "there is no want of means for providing illustrations to papers communicated to us for publication."

I have felt it to be my duty to you to enter with some detail into Dr. Williams's earnest appeal to me. There remains to inform you of the constitution of the Committee, and of the result of their labours.

Most fortunately the services of five Fellows were obtainable for this Committee, who were, of any in the Society, perhaps the most competent to aid its deliberations—namely, Drs. Guy and Farr and Mr. Merrifield as statisticians, and Mr. Justice Grove and our late Secretary, Dr. Sharpey, as having taken a very prominent part in the discussion which in 1847 terminated in the adoption by the Society of that mode of election which has been followed ever since, and has raised the Society to its present position. It is well perhaps that, in a matter so deeply affecting the welfare of the Society, I should name the other members; they were Dr. Williams himself, and Mr. John Evans, together with the President and Officers, making a Committee of twelve in all. The following is the Report which they have made to the Council:—

"*Report of the Election Statutes Committee.*—The Committee appointed to consider whether it is desirable or not to make any alterations in the Statutes relating to the Election of Fellows, have given to the subject the careful consideration demanded by the importance of these Statutes, not only to the Royal Society, but to the general body of workers in science in the kingdom.

"The status of the Royal Society and the widespread recognition of the value of its Fellowship render it highly desirable that, while on the one hand no one shall be admitted to the Society who is not worthy of the honour, on the other, no one who is worthy shall be excluded from the Society, nor even suffer undue delay in entering it.

"At the outset of their deliberations, the Committee unanimously agreed to recommend the maintenance of the principle of the existing Statutes; that is to say, to leave in the hands of the Council, as at present, the duty of selecting the Candidates to be presented to the Society for election.

"They further agreed, *nemine contradicente*, that the number so selected annually ought to be limited.

"The only questions that remained therefore were, ought the number thus limited to be less than at present, greater than at present, or to remain as it is? And, practically, the choice was limited to the last two alternatives.

"As a preliminary to the discussion of these alternatives, the Committee thought it desirable to ascertain what may reasonably be expected to be the strength of the Society if the present limitation remains in force.

"The answers of the Fellows of the Society to a circular addressed to them by the Committee, together with other statistical evidence as to the age at election and the average duration of life of the Fellows, have been carefully considered by several Members of the Committee who are specially qualified to form a judgment on such matters; and their conclusion is that, under the present mode of election, the average number of Fellows, exclusive of the Foreign Members, may be expected to be about 430.

"Considering that the Royal Society is no longer, as at the time of its foundation, the only scientific corporation in the kingdom, but that numerous Societies have arisen devoted to one or other of the sciences, it appears to be thought generally desirable that the Royal Society should be distinguished by consisting of those persons who may be regarded as the representatives of, or the most active and successful workers in, the different departments of science, in association with promoters of scientific research and men of signal eminence in statesmanship, art, or letters.

"The Committee have carefully considered whether the present limitation of annual selection to fifteen entails any undue delay in the election of persons who answer to the foregoing description into the Royal Society. They find no ground for asserting that it does, and therefore they have unanimously agreed to recommend that no change be made in that number at present."

I now pass on to review the part taken by the Society in furtherance of various Government and other expeditions.

The Polar Expedition.—Early in December last year a letter was received from the Admiralty stating that Her Majesty's Government had determined to despatch an expedition to endeavour to reach the North Pole and to explore the coasts of Greenland and adjacent lands, asking at the same time for suggestions on the part of the Society in regard to carrying out the scientific conduct of the Expedition.

The great importance of attaching Scientific Naturalists to such an expedition having been represented to the Government, the Society was informed in January last that the Lords Commissioners of the Admiralty were prepared to appoint a Naturalist to each ship, and was asked to recommend two candidates who should be selected for their acquaintance with as many branches of Natural History as possible.

In pursuance of this intimation, your Council recommended to the Admiralty as Naturalists, Mr. Chichester Hart, M.A., of Trinity College, Dublin, and Captain Feilden, R.A., gentlemen well recommended to us for their acquirements, both as Naturalists and collectors, and having special qualifications for so arduous an enterprise; and, further, applied for a grant of £250 to meet the expenses of editing a scientific manual for the use of the Naturalists and Officers generally. This application having been favourably entertained, Professor Rupert Jones was requested to undertake the compilation and editing of the Biological and Geological portions of the

Manual, and Professor Adams, of King's College, the Physical. The Scientific Instructions to the Naturalists and Officers were contributed by the most competent persons (who, with two exceptions, were Fellows of the Society) whose services the Council could obtain. The whole was published in May, under the title of 'The Natural History, Geology, and Physics of the Arctic Regions,' and forms, with the Scientific Instructions, an octavo volume of more than eight hundred pages.

In connexion with the Polar Expedition I have to mention the cruise of H.M.S. 'Valorous,' which took out to Disco stores for the two ships. On the representation of Dr. Carpenter in a letter addressed to myself, an application was made by your Council to the Lords Commissioners of the Admiralty to employ the 'Valorous' on her return voyage in making deep-sea and temperature-soundings in Davis's Straits and the North Atlantic, and to grant a passage to Mr. Gwyn Jeffreys, F.R.S.; and an assistant, and thus take advantage of so favourable an opportunity for continuing in the Arctic Sea those scientific researches which he had so successfully conducted in H.M.S. 'Porcupine' in 1869 and 1870.

The application was at once granted; and although the voyage was far from prosperous, the weather having been tempestuous and the 'Valorous' having been in danger a few hours through striking on a sunken rock, the results have been generally satisfactory, and include many new species of pelagic animals. Captain Loftus Jones and Mr. Jeffreys dredged on the Greenland coast from 70° 30′ N. lat. to the entrance of Davis's Straits, and in the Atlantic as far as 25° 58′ W. long., in depths of which the greatest was 1785 fathoms; and temperature-soundings were taken at eleven out of the twenty stations indicated in the Admiralty Instructions.

Among the valuable results obtained is the fact that the fauna of the Greenland seas agrees with its land flora in being mainly Norwegian, there being (with the exception of the Echinoderms) an absence of many North-American forms, which, as it appears, have not been found eastward of the meridian of Cape Chidley in Labrador. A remarkable mollusk, previously dredged at a depth of about 1000 fathoms off the coast of Portugal by the 'Porcupine,' and which, when first found in a fossil state in the newer tertiaries of Sicily, was supposed to be an extinct type, reappears in the deep waters of Davis's Straits; and a *Campanularia* was found, specifically identical with one discovered this year in the opposite hemisphere, viz. in Kerguelen's Land, by Mr. Eaton, the Naturalist of the Transit-of-Venus Expedition to that island. A most singular sponge-like diatom, named by Dr. Dickie *Synedra Jeffreysi*, with living *Globigerinæ* entangled in the colloid connecting-matter of its frustules, was taken in the towing-net.

The existence of a remarkable elevation of the floor of the ocean was ascertained in lat. 56° N., long 34° 42′ W., where soundings of 690 fathoms were obtained between depths of 1450 fathoms on one side and 1230 fathoms on the other—an interesting fact when taken in connexion with H.M.S. 'Bull-dog' having found a similar elevation in lat. 59° 40′ N. and long. 29° 30′ W. It makes known the probable existence of a sub-oceanic ridge running N.E. and S.W. between Great Britain and Greenland.

Naturalists to the Transit-of-Venus Expeditions.—On the recommendation of the Council, as I stated last year, Her Majesty's Government attached a Botanist (who was also Geologist), a Zoologist, and a Cave Explorer to the Expeditions despatched to Rodriguez, and a Naturalist to the Kerguelen expedition. These Naturalists have returned, Messrs. Balfour, Gulliver, and Slater from Rodriguez, and the Rev. A. E. Eaton from Kerguelen's Land, bringing collections and observations in all respects justifying the objects sought, and the Council's choice of agents for obtaining them.

As regards Rodriguez, the most important result obtained (and it was a very unexpected one) is that, whereas in all preceding accounts of this island it has been described as consisting of a nucleus of granite with flanking beds of sandstone, limestone, and other aqueous rocks, and hence seemed to afford a rare example of a non-volcanic oceanic island, Mr. Balfour shows that neither granite nor sandstone there exist, and that it is composed wholly of igneous rocks, with patches of coralline limestone along the coast. It belongs therefore geologically as well as geographically to the Mascarene group, of which it is a distant outlier, and not to the Seychelles group, as had been erroneously suspected.

The general characters of the Fauna and Flora of Rodriguez were found, in accordance with its geology, to approximate very closely to those of the Mauritian group, upwards of 300 miles to the westward, and not to partake of the distinctive features of the Seychelles, which are Indian rather than African. What differences there were from the former indicated relationships with far distant countries, and some of them were extremely curious.

The greatest interest no doubt attaches to the extinct animals, chiefly Birds and Tortoises, whose remains are found in the caves of Rodriguez, and which, though extensively collected by Mr. Newton and described by himself, by Dr. Günther, M. Milne-Edwards, and other authors, were still but very imperfectly known. Of Birds Mr. Slater found remains of thirteen species, of which six are extinct; one is found living in Bourbon alone, and one of the extinct species is new to science. Of the famous Solitaire (the Rodriguez representative of the Dodo) materials for the construction of a complete skeleton were obtained, together with more complete specimens of other birds first described by M. Milne-Edwards from a few fragments. The shells and bones of three extinct Tortoises were obtained in great abundance, together with those of a large Skink, said to be still living in the island, but of which no certain information could be obtained.

Regarding the circumstances under which the remains were preserved, Mr. Slater finds, from an examination of twelve caves, that these were all formed by the action of water on coralline limestone, but that the beds of earth in which the bones were deposited, and which vary from two to nine feet in depth, are of basaltic material washed or blown into the caves. Mr. Slater brings forward evidence in support of the hypothesis that the birds were entombed subsequent to the visits of Europeans, and that their entombment is due to their having taken shelter in the caves during the fires that ravaged great parts of the island; and that elsewhere the Solitaire has been extirpated by imported cats and pigs, the former of which, of large size and great ferocity, still abound.

With regard to the Tortoises, the remains of which are extraordinarily numerous in the caves, there is evidence of their entombment having been subsequent to that of the Birds; but the direct cause of their extinction is not apparent. Another noteworthy fact is that, whereas the marshes of Mauritius have yielded the greatest number of Dodo remains, those of Rodriguez appear to contain no bones of its ally the Solitaire or of any other bird.

Mr. Slater's fine collection was, by permission of the Council, exhibited at Professor Flower's Soirée at the Royal College of Surgeons in July last, and attracted great attention.

Mr. Gulliver has brought home an extensive collection of the animals of the island, among which all classes are represented except some of the Vertebrates; of these last the most numerous are the Birds, which had previously been described by Professor Newton. Ophidians are totally absent; and Amphibia also, although there are swamps of some extent. The spiders seemed to abound; and some new forms were collected, one with an arrangement of the eyes that is unique in the class; and another spins a web so strong as to be used by the settlers as cobblers do "waxed ends."

The representation of winged insects by wingless allies, which is so remarkable a feature in other oceanic islands, is not alluded to by Mr. Gulliver as characteristic of the insect fauna of Rodriguez; nor has he observed any correlation between the insects and flowering plants in respect of the fertilization of the latter.

Mr. Balfour's report on the Flora of Rodriguez is a very full one; it refers exclusively to living plants; for though several of these are almost extinct, no traces of fossil leaves or other parts of plants were found with the birds' and tortoise bones or elsewhere.

More than one half of the island appears to have been denuded by fires of its indigenous vegetation, which has been replaced by introduced species that are for the most part common social tropical weeds. The soil is now for the most part arid, whence even the Ferns, of which upwards of 20 species were found, are typical of dry regions. About 300 flowering plants were collected; and, as usual in insular floras, the proportion of species to genera, and of these to orders, is very much smaller than in continental areas. Thirty-three species, belonging to as many genera, are peculiar to the island, and two of them belong to new genera.

It is a very remarkable fact that one of these new genera, belonging to the Natural Order Turneraceæ, is most closely allied to a peculiar Panama genus; and that one of the new species has only a single congener, which is a Pacific island plant. There are three Palms, all of them peculiar, and two Screw-pines (*Pandani*). Dr. Balfour remarks the extraordinary number of plants whose leaves vary in form at different ages. For other matter, much of it very curious, I must refer to the three Reports, which will in due time be published, with sufficient illustrations.

Mr. Eaton's valuable Report on the Natural History of Kerguelen's Land having been already before you, and printed in our 'Proceedings,' requires no further mention here.

There remains to state that your Council has found reason to express satisfaction with the Reports and Collections of all the Naturalists; that complete catalogues of the specimens procured will appear in our publications; that the detailed descriptions and observations will also be published, either by the Naturalists themselves or by competent persons; that the specimens will be distributed after a complete set has been reserved for our National Collections; and that the total expenditure amounts to £1512, of which £1396 was contributed by Her Majesty's Government, while the rest has been defrayed out of the Donation Fund.

The Total Solar Eclipse of April 1875.—Towards the close of last year the desirability of observing the total eclipse of the Sun, which was to take place in India, engaged the attention of your Council; and the subject was under its consideration when a letter was received by me from His Majesty the King of Siam, offering hospitality and assistance should the Royal Society deem it expedient to appoint scientific men to observe it from His Majesty's dominions.

Your Council being of opinion that both the importance of the occasion (totality during this eclipse being of longer duration than during any other that would be observed in the present century) and the liberal offer of His Majesty required careful consideration, appointed a committee of five astronomers and the Society's Officers to report upon the feasibility of undertaking such an expedition with a reasonable prospect of success. The Committee was advised that no time was to be lost in arriving at a conclusion, as only four months would elapse before the occurrence of the eclipse.

The first step taken was to communicate with the First Lord of the Treasury and the Secretary of State for India, and ascertain whether, should the attempt be made, Her Majesty's Government would be disposed to cooperate with the Society.

The answers were most favourable; but still grave doubts were entertained by several of the Committee as to whether it were possible to make the necessary preparations and arrangements with sufficient completeness to secure adequate results.

After much deliberation it was decided in the affirmative, the Committee's decision being based on the following favouring circumstances:—That confidence in its feasibility was expressed by those members of the Committee who had themselves conducted or accompanied Eclipse Expeditions in foreign countries; that two eminent observers, Messrs. Janssen and Tacchini, were already in India and their services available; that Her Majesty's Government would cooperate by proposing to Parliament a grant in aid of £1000, which would be augmented by another of £300 from the Donation-Fund of the Society; that the Secretary of State for India and the Governor-General of India had promised active cooperation by sending an expedition to the Nicobar Islands, where, as well as in Siam, totality would be visible; that both the Indian Government and the Admiralty had granted passage in their vessels, and that the Peninsular and Oriental Company had offered to give passage to the observers and their assistants at greatly reduced rates; that His Majesty the King of Siam would defray all expenses of the party sent to his territories; and lastly, which perhaps weighed most with the Committee, was Mr. Lockyer's disinterested offer to superintend all the arrangements of observers and instruments, to prepare the instructions for their guidance abroad, and to make all the necessary telegraphic and other communications with India and the Straits Settlements previous to and during the progress of the Expedition.

As in the case of former Eclipse Expeditions, invitations to take part in the observations were addressed to foreign men of science distinguished for their researches in solar physics; but Professor Tacchini was the only one who could accept. At the same time Dr. Vogel, of Berlin, a well-known photographer, was asked to assist, and he accompanied the Expedition.

A communication was received from M. Dumas, the perpetual Secretary of the Paris Academy of Sciences, with reference to Dr. Janssen's proposed observation of the Eclipse; and instructions were sent to Singapore that every assistance should be afforded to that distinguished physicist.

As a final result of these preliminary arrangements, there were two strong parties in position on the morning of the 6th of April, of whose members no less than six were sent out from England. One party, a combination of Italian, Indian, and English, went to Camorta in the Nicobar Islands; the other, French and English, made their way to Chulai Point in Siam. In the first party were Professor Tacchini, Captain Waterhouse, Professor Pedler, Dr. Vogel, and Messrs. Meldola and Reynolds; in the second were Dr. Janssen, Dr. Schuster, and Messrs. Lott and Beasley, each amply provided with assistants.

The Committee decided that at both stations the observations should be mainly photographic; and the instruments furnished had for their object the registration of the violet spectrum of the corona and chromosphere as a whole, and that of the spectrum of an isolated portion of the image.

Ordinary photographs of the corona and of the polariscopic effects of its light were also provided for.

In spite of the most hopeful anticipations, the weather at Camorta proved bad on the morning of the Eclipse, and, as has been observed on former occasions, the reduction of the temperature, due to the withdrawal of the sun's heat, produced a mass of cumulus cloud which prevented a most thoroughly equipped party from making any observations whatever during totality.

The success of the Siam party has been also far less than was anticipated. An unfortunate break-down in the Suez Canal, and some misunderstanding, in consequence of which the promised Government steamer was not forthcoming, caused delays which left so little time for the final adjustment of the instruments when the observers at last reached their station, that some records are altogether wanting; and the attempt to photograph the spectrum of an isolated portion of the chromosphere proved a failure.

The most important results obtained are (1) a series of photographs of the corona, taken with a prism of small angle in front of the object-glass, which show several rings and part of the form of the outer corona, and (2) a series of views of the corona, chiefly taken at different times of exposure. The discussion of the observations has not yet been taken in hand; but it is not too early to state that several results of great interest and value have been secured.

The King of Siam himself made a sketch of the corona and forwarded it to the Society. In common with others which accompany the Reports, it does not differ very greatly from the figure photographed on the plate.

I cannot conclude this short reference to one branch of our activity during the past session without congratulating English Science upon the fact that the Eclipse was not suffered to pass unobserved, and without expressing our obligations to all those whose names will be mentioned at length in the Report, who both here and abroad at each stage of the arrangements afforded us valuable assistance, not forgetting the observers themselves, who in the service of science volunteered for a duty not without risk, and from the performance of which, indeed, some have suffered in health.

The 'Challenger' Expedition.—The third year of the 'Challenger's' voyage has been no less fruitful of results than the two preceding; which is the more satisfactory, as she has lost the services of her indefatigable Commander Captain Nares, who, as you are aware, has been summoned home to command the Polar Expedition. Interesting discoveries seem literally to have crowded along the course of this vessel, and the scientific storehouses of the deep to have been unlocked at the bidding of Professor Thomson and his busy and able staff. It would be premature to estimate as yet the probable importance to Biology, Geology, and Physical Geography of the grand but still imperfect generalizations which are being drawn from the facts sent home from the ship as to the nature and distribution of those microscopic forms of pelagic life, the Foraminifera and Radiolaria; but there can be no doubt that our knowledge of the formation of Azoic clays and schists, and of the processes of metamorphism at great depths, is being greatly enlarged by the operations of the 'Challenger' Expedition. Nor are the discoveries in submarine geography of less interest—such as the finding in the Melanesian Pacific areas which, though only partially circumscribed by islands, exhibit biological and hydrographical phenomena differing widely from those of the circumambient ocean. In the depths of the sea, as on the surface of the land, are contiguous areas peopled by very different assemblages of living things. As on the land we ascend to meet a colder temperature, accompanied by forms of life of wider distribution than at lower elevations, so in the seas of warm and temperate regions we descend to meet with analogous conditions. The ocean thus mirrors one of the most striking features of the distribution of terrestrial life, and, mirror-like, it turns the picture upside down. Furthermore, this analogy is confined to the warm and temperate zones of the sea: in the cold zones this order of things is reversed; there, as on land, we descend to warmer temperatures, and the deepest sea is peopled by animals proper to a much lower latitude. The total result is a uniformity in the general distribution of oceanic life that has no parallel on land; and facts in the migration of marine animals and plants that were formerly accounted for by assuming that they possessed greater powers of withstanding changes of temperature, are now accounted for by conditions more closely resembling those that obtain on the land.

From such considerations as these it would follow that pelagic life should be less differentiated than terrestrial; and no doubt it is so; and to a still more considerable degree is lacustrine and fluviatile life less various than pelagic, in respect of plants especially. On the other hand, whereas both the mass and variety of vegetable life is much greater on land, the bulk, but not the variety, of animal life is much greater in the ocean. It is no doubt owing to the infinite variety of food that terrestrial animals have access to, rather than to the diversities of climate, soil, and other conditions, that the land presents so much greater a variety of life than the sea does. It is true that local assemblages of marine plants have their local faunas, as the Sargasso Sea and the vast *Macrocystis*-

meadows of the southern ocean; but in such cases it is shelter, not food, that has localized the assemblages. But this reminds me that I am becoming discursive; and I will conclude my digression by referring to the rarity of its phytophagous animals, as being to me one of the most wonderful and inexplicable phenomena of oceanic life; for with the exception of those that live upon the ubiquitous pelagic Diatomaceæ, there are very few marine animals of general distribution or of any size that feed on marine plants.

While these words were being penned the sad tidings have reached us of the premature death of one of the brightest intellects and most cultivated members of the 'Challenger' Scientific Staff, R. von Willemöes-Suhm, whose beautiful paper, "On a new Genus of Amphipod Crustaceans," appeared in our 'Transactions.' This admirable piece of work will soon be followed by a second from his pen on Cirripedes, illustrated by six plates, and a third on the development of certain pelagic Decapod Crustaceans. His loss, which occurred on board off Tahiti, and was due to erysipelas, is, indeed, an irreparable one, and cannot but cloud the last year of the 'Challenger' voyage.

The protracted absence of H.M.S. 'Challenger,' and the great importance in the interest of science that the Director of its Scientific Staff, Professor Wyville Thomson, should not leave the Expedition, has, by detaching that gentleman from his duties in the Natural-History Chair of the Edinburgh University for so much longer a period than was anticipated, placed that University in a very difficult position, and obliged its Court to appeal to the Society. It was originally arranged that the duties of the Chair should, for the first two years of Professor Thomson's absence, be undertaken by Professor Carus, of Leipsic; on the third, Professor Carus being compelled to return to Germany, the University Court represented to the Lords of the Council that, having regard to the fact that Professor Thomson was withdrawn from his professorial duties by Her Majesty's Government, and in accordance with the strong recommendation of the Royal Society, it was not unreasonable to hope that both the Government and the Society would come to their aid by permitting Professor Huxley to deliver the University course of Lectures. The Lords of the Council having granted the permission, your Council did not hesitate to make such arrangements as enabled Professor Huxley to absent himself from the Society for the purpose required. The result has in no way inconvenienced the Society; Professor Huxley managed to attend the Council-Meetings, he conducted at a distance the editorial work that belonged to him, and such of his duties as could be performed only on the spot were kindly undertaken by Professor Stokes.

I have only to add that Professor Thomson's return being further delayed till July 1876, Professor Huxley's services have again been applied for by the University Court; and, having been granted by the Lords of the Council, similar arrangements for his absence to those which obtained last year will be made by the Council for the months of May, June, and July of 1876.

The Meteorological Committee.—The anomalous connexion between the Royal Society and the Meteorological Office on the one hand, and between that Office and the Government on the other, to which and its consequences I drew your attention in my last year's Address, is likely soon to be terminated, the Lords Commissioners of the Treasury having appointed a Committee to inquire into the working of the present Office and the value of the results hitherto obtained.

Seeing that the operations of the Committee have been generally in a great measure tentative, and have now extended over nine years, this action of the Government is viewed with satisfaction by the Committee, whose arduous services have been entirely gratuitous during this long period. The value of their labour is indeed fully recognized in the Treasury Minute appointing the Committee, which expresses absolute confidence in its efficiency, but thinks that the time has arrived for further inquiry.

According to the instructions of the Treasury, the inquiry is to be directed to two principal points of scientific interest, viz.:—

(1) How far the statistics hitherto collected have led to the discovery or confirmation of Meteorological Laws.

(2) How far the principles upon which storm-warnings are given have been justified by results.

I need hardly observe that these questions open up a very wide field of inquiry of the highest importance to the meteorology of the future, whether in this country or elsewhere. There can be no question but that the Committee has rendered most important services to science and to the country; it is held in just estimation among continental physicists, and its methods and results have been in a great measure adopted and followed by them, in many cases without modification.

Still the geographical position of the British Isles is one that renders meteorological inquiry full of difficulty, and hence necessitates a very careful periodic supervision of the measures employed to advance its theories and to apply them to practice. Unlike the Atlantic States of America, we have no area to the westward of us (which is emphatically our storm-bearing quarter) upon which we can establish recording stations. We can have no system like that of the American meteorologists, which would enable us to obtain that knowledge of the atmospheric disturbances over the Atlantic which they can procure of those which extend over the continental area to the westward of their central Observatories.

On the other hand, England has advantages for promoting the study of terrestrial meteorology that no other country has—namely, her foreign possessions and Colonies, and the command of the telegraphs with which the ocean is in process of being crossed in every direction. We have known what it is to read at our breakfast-tables telegrams from all parts of the world of the prices of stocks and of political incidents of the previous day; why should we not, then, obtain daily statistics of the climatic conditions of these and other remote regions, and inaugurate in England a system of meteorological registration which, if its elements were obtained from but a few well-selected spots, would instruct and interest every intelligent person in the climate of the globe, and in the end lead to scientific results of great value? We must remember that it is not the policy of the Government of this country in its view of the present state of public feeling, and as expressed in the Minute appointing the Committee, to give direct assistance to the study of any science except with a view to the more immediate application of scientific theories to practical purposes, in which the public rather than individuals have a direct interest. Whatever may be thought of the wisdom or soundness of this policy (and in the opinion of some eminent scientific men it is wise and sound), we must shape our course accordingly, doing our endeavour never to allow scientific investigation to be subordinated to practical results; but keeping it ever in advance, remembering too that the Government estimation of the value of scientific investigation is measured more by the amount of interest which it excites than by any standard of its own; whence it follows that the Government is not slow in encouraging researches that interest and instruct the public, whether or not they may be seen to lead to direct practical results. Keeping these facts in view, I cannot but think that the Committee of the Treasury will have the opportunity of recommending to Her Majesty's Government the adoption of measures that would greatly increase the scientific efficiency and public interest of the Meteorological Office.

The Gilchrist Trust.—In my last year's Address I announced that arrangements had been made by the Council for the administration, under the authority of the Trustees of the Gilchrist bequest, of a grant of £1000 per annum in promoting original research, thus aiding in the fulfilment of the wishes of the Testator, that the proceeds of his large fortune should be devoted "to the benefit, advancement, and propagation of education and learning." The scheme for the administration of this grant was approved by the Trustees and laid before you in detail; but since then its operation has been frustrated by a most unexpected judicial decision formally given in the House of Lords as to the meaning to be assigned to the terms of the Gilchrist bequest—namely, that "the promotion of original research" could not be held to be "benefiting the advancement and propagation of education and learning," for that it was expressly laid down by the Law Lords that "learning is to be construed as synonymous with education," and that the whole fund is to be devoted to the *propagation* of knowledge.

This is not the time *or place to comment* upon what must appear to us to be a very strange limitation of the Testator's wishes; I can only hope that a more enlightened posterity, the outcome of a more liberal and scientific education than now obtains, will introduce into the theory and practice of the Law an interpretation of the "advancement of learning" more in harmony with scientific ideas and the requirements of the age. In the mean time it is much to be wished that the prize thus snatched from so high a purpose may yet be made to contribute in some way to the advancement of original research; and I feel sure that it will be due to no want of energy and goodwill on the part of the Trustees and of their Secretary, Dr. Carpenter, nor of hearty cooperation on the part of the Royal Society, if science reaps no benefit from the Gilchrist Trust.

The Government Loan Collection of Scientific Instruments.—It affords me much pleasure to refer to an action on the part of Her Majesty's Government which we may anticipate will lead to important results to the cultivation of Science in this country. I mean the Loan Collection of scientific instruments which is to be formed at South Kensington in the course of the ensuing year. The Lord President and Vice-President of the Council, in introducing this subject to the first meeting of the men of science to whom they have applied for assistance, shadowed forth their own views and hopes that the collection might prove the commencement of governmental action with regard to one of the recommendations of the "Science Commission"—that, namely, dealing with the present want of a museum illustrating the sciences of experiment and observation. The Government has further suggested to the various continental governments the appointment of Commissions, composed of the most eminent men of science, to which we may confidently look for help in selecting the most important instruments that illustrate the history, the advancement, and the spread of science.

In the proposed Exhibition not only are modern scientific methods and instruments and the various methods of practical instruction in science to be fully dealt with, but it is also proposed that the history of science shall be illustrated by the actual instruments which have been employed, from the time of Galileo downwards, in those critical experiments and discoveries which mark the principal stages along the road of progress.

The men of science of this country have already responded so warmly to the appeal made to them, that it is not necessary for me to commend the proposed action to them; and I may conclude my reference to this subject by the expression of a hope that our fellow-workers in other countries will not rest content with sending their instruments, but will accompany them to London, so as to enable us to assure them personally of our esteem.

On the motion of Sir Thomas Watson, seconded by Sir Alexander Armstrong, it was resolved—"That the thanks of the Society be returned to the President for his Address, and that he be requested to allow it to be printed."

I now proceed to the presentation of the Medals.

The Copley Medal has been awarded to Professor August Wilhelm Hofmann, F.R.S., of Berlin, for his numerous contributions to the science of Chemistry, and especially for his Researches on the Derivatives of Ammonia.

The researches of Dr. A. W. Hofmann, from first to last, are related by a strict logical connexion, from which (although in various side-paths he has made truly interesting discoveries) he has never essentially deviated. Indeed these researches may be considered as constituting one great and prolonged research on the organic bases theoretically and experimentally considered. It is not, however, to be imagined that because, to a certain extent, limited in its range, this work is of a special or technical order. The subject covers a large area, and is calculated to lead the investigator to the consideration of the most important chemical problems.

The memoirs of Dr. Hofmann in reference to the organic bases fall under several heads:—(1) The researches on Aniline and the organic bases contained in Coal-tar. These researches are mainly included in the period between 1843 and 1850. (2) The investigations on the molecular constitution of the organic bases derived by the substitution of the Alcohol radicals in the molecule of Ammonia (1850–51). (3) The Phosphorus bases and the Diatomic ammonias (1857–60). (4) The investigations on Rosaniline and the various Colouring-matters derived from Coal-tar (1860–70).

In the course of the Aniline investigations Hofmann made an important contribution to the Unitary theory of Chemistry. Dumas had shown that the essential chemical properties of acetic acid were not altered by the substitution in the acid-molecule of chlorine for hydrogen; but no organic base had yet been discovered derived from another base by a similar process. Fritsche, indeed, had made a bromine-derivation of aniline, in which three atoms of hydrogen were replaced by bromine; but the substance thus formed was a neutral (not basic) body. It occurred to Hofmann that the substitution had here gone too far, and that for this reason the basic properties of aniline had disappeared. Consequently, by an ingenious process (devised for the experiment), the treatment of chlorisatin by the hydrate of potash, he prepared monochloraniline—aniline, that is, in which one atom of hydrogen was replaced by chlorine. This body was a base, like aniline itself. Hofmann established its basic character by the preparation of many of its salts (Liebig's 'Annalen,' vol. liii. p. 1, 1845).

At the date when Hofmann's paper on the molecular constitution of the volatile organic bases was presented to the Royal Society (December 1849), Wurtz had just *prepared, by* a striking experiment, the primary monamines of the alcohol radicals—that is, a system of bases in which one third of the hydrogen of the ammonia was replaced by the hydrocarbon, the existence of which (it may be noticed) had been predicted by Liebig as a consequence of his views as to the composition of the organic bases. The experiments of Hofmann were in the same direction as those of Wurtz, but of far more general application. By the action of the iodides of the alcohol radicals upon ammonia, Hofmann replaced successively the three atoms of hydrogen which its molecule contains by these hydrocarbons—a method fraught with important results, both theoretical and practical, with which all chemists are familiar.

Among other consequences, this method placed the theory of types on a solid experimental foundation, which served as the basis of its future development. A critical test was given, by which the constitution of any given "ammonia" could be ascertained, the number of derivatives of the "ammonia" when subjected to the action of iodide of ethyl corresponding to the number of atoms of hydrogen which it still retained unreplaced by hydrocarbon. Hofmann applied this test to aniline, and demonstrated, by the successive formation of ethyl-aniline and diethyl-aniline, that this base belonged to the primary monamine class, containing two atoms of hydrogen unreplaced by hydrocarbon. To trace out, however slightly, the consequences of this method would be a serious task indeed. It is sufficient to say that the views at present held by chemists as to the molecular constitution of water, according to which water is regarded, like ammonia, as a typical molecule, but containing two atoms of hydrogen (instead of, as in the other case, three) replaceable by the alcohol radicals, are based upon experimental evidence for which the very same instrument of research, the iodide of ethyl, and methods in all respects analogous to those by which Hofmann thus established the constitution of aniline were employed.

According to these views triethylaniline represented ammonia in which all possible substitutions of this order had been effected. However, Hofmann applied his test to this substance, and obtained a most remarkable result. A molecule of iodide of ethyl combines with a molecule of this substance, giving rise to the iodide of a molecular group, behaving like potassium or sodium, "a true organic metal in all its bearings." The ground of this assertion is, that this iodide of tetrethylammonium, when treated with freshly precipitated oxide of silver, is decomposed with the formation of an oxide of the "organic metal" possessing the main features of potash. This train of investigation has not as yet been adequately pursued; but the fundamental importance of this experiment, in reference to our knowledge of the elemental bodies, cannot be doubted.

The first memoir on the Phosphorus bases, in which the existence of a class of phosphorus bases analogous to the compound ammonias was experimentally established, was published in conjunction with M. Cahours. In three subsequent memoirs these compounds were further investigated with the determination of the differences by which they were discriminated from their nitrogen analogues. We have here presented to us the first example of a diatomic base formed by the action of bromide of ethyline or triethyl-phosphine, in which reaction (as in the similar case of the diatomic alcohols) Hofmann successfully established the formation of an intermediate monatomic bromide, the reaction taking place by two distinct stages. In the third of these memoirs a new class of compound bases is brought before us, containing both nitrogen and phosphorus. Subsequently, in a series of somewhat less elaborate memoirs, the conception of the typical character of ammonia is greatly expanded by the examination of the derivatives of two and three molecules of ammonia.

As to the researches in reference to the colouring-matter derived from coal-tar, it is only necessary to observe that his inquiries initiated and rendered possible what is now a vast branch of industry. In reference to rosaniline itself (the key of the system), he established the fact, long unknown, that this substance was not an aniline compound at all, but derived from the combination of aniline with toluidine.

I may lastly mention, as a fitting conclusion to this series of discoveries, an investigation of very wide interest, which has resulted in the construction of the normal cyanides (α) of the monatomic hydrocarbons, formed by the action of chloroform on the primary monamines, which, together with water, are resolved into formic acid and the base whence they are derived; while their isomers (Class B), the nitrites, under similar conditions yield ammonia and their corresponding acids. Hofmann has also established the existence of a new class of cyanates (β) of the same monatomic hydrocarbons which, together with water, are resolved into ammonia and their corresponding alcohols, the original class (α) being resolved under the same circumstances into carbonic acid and the primary monamines, as in the experiment of Wurtz before referred to, the whole investigation standing in intimate connexion with Hofmann's previous work.

To estimate the value of these results it is necessary to go through the vast mass of experimental evidence from which they are deduced, which constitutes a body of complete and exact information in reference to one general subject not easily paralleled in the history of Chemistry.

The Medal was received by Dr. Hofmann.

A Royal Medal has been awarded to Mr. William Crookes, F.R.S., for his various chemical and physical researches, more especially for his discovery of Thallium, his investigation of its compounds, and determination of its atomic weight; and for his discovery of the repulsion referable to radiation.

In the year 1861 Mr. Crookes communicated the discovery of a new element, which he had detected by means of a green line exhibited in the spectrum of certain selenium residues which he was examining for tellurium. The element had as yet been found in extremely small quantities only; but yet he was able to prove chemically as well as optically that it was a new substance, which, from some of its reactions, he thought most probably belonged to the sulphur group of elements, and to which he gave the name Thallium.

The investigation of this new substance was eagerly followed out; and by inquiries in various directions he succeeded in obtaining it in larger quantities, though his supply was still most inconveniently small, rendering it necessary to work the same material over and over again, instead of carrying on the investigation of two or more of its compounds simultaneously. This investigation, which had led him to perceive that the new body was a metal, which he isolated, was in progress when (in the summer of 1862) he was induced to send in a preliminary notice of his investigations to the Royal Society, instead of waiting, as he had intended, till the research was complete, in consequence of the publication by M. Lamy (who had been fortunate enough to meet with a comparatively fertile source of the new substance) of a paper in which he described several of its compounds and announced its metallic nature. The complete memoir was presented to the Royal Society early in 1863, and is published in the 'Philosophical Transactions' for that year. It contains, among other things, a provisional determination of the atomic weight, giving a mean result of 203·96.

The atomic weight of an element being a constant of fundamental importance, Mr. Crookes spared no pains in an accurate determination of that of thallium. This research, which extended over several years, is described in a highly elaborate memoir which was presented to the Royal Society in 1872, and is published in the 'Philosophical Transactions' for the following year. The various weighings which the investigations required were performed and reduced with the most scrupulous regard to minute accuracy, as the utmost care was taken in the preparation of the chemicals. Though only one method was employed, namely that of determining the weight of nitrate of thallium obtained from a known weight of the metal, the care with which the whole process was conducted, and the near agreement of the different experiments, are such as to lead us to regard the final mean 203·642 as most probably very near the truth.

In the course of the weighings which were executed in this research, Mr. Crookes noticed some minute anomalies depending on temperature which did not seem referable to currents of convection. This led him into a train of experimental research which resulted in the discovery of an action of radiation which, whatever be its real nature (a point still involved in mystery), and whether the action be direct or indirect, all who have seen or followed the experiments must allow to be most remarkable. An account of this research was published in the 'Philosophical Transactions' for 1874.

When delicate beams of straw and other materials, carrying pith balls or disks at their ends, were mounted so as to turn as freely as possible within glass vessels from which the air could be exhausted, it was found that at atmospheric pressure the approach of a hot body produced a movement usually indicative of an attraction, real or apparent, between the ball and the body, and that of a cold body a reverse movement. In these motions, however, it is evident that currents of convection play a leading part; nor does it appear by any means certain that the actions may not be due to these and other well-known causes. The same thing continues when the air is partially exhausted, until, at a certain high rarefaction varying according to circumstances, the motions cease, or nearly so. But on passing this, a new and unexpected phenomenon is revealed, which is exhibited in perfection in chemical vacua, and in the best vacua produced by the Sprengel pump with the improvements which Mr. Crookes has introduced into it. The suspended body is now repelled with striking energy when a source of radiant heat or light is presented to it, or even, if the radiation be powerful, when it is held at some distance, or when the sun's rays concentrated by a lens are thrown upon it. The action has more recently been exhibited by Mr. Crookes in an exceedingly striking form by means of a horizontal 4-armed fly delicately mounted on a sharp point, and carrying at the ends of the arms pith disks in vertical planes passing through the arms, the disks being blackened on one face, on the same side for all. The motion depends in this case on a differential action on the black and white faces, the black being repelled.

It is the mystery attending this phenomenon that gives it its great importance. There is evidently some action going on with which we are not at present acquainted; and there is no saying what a thorough investigation into the cause of the phenomenon may lead to.

The Medal was received by Mr. Crookes.

A Royal Medal has been awarded to Dr. Thomas Oldham, F.R.S., for his long and important services in the Science of Geology, first while Professor of Geology in Trinity College, Dublin, and Director of the Geological Survey of Ireland, and chiefly for the great work which he has so long conducted as Superintendent of the Geological Survey of India, in which so much progress has been made that in a few years it will be possible to produce a Geological Map of India comparable to the Geological Map of England executed by the late Mr. Greenough; also for a series of volumes of Geological Reports and Memoirs, including the 'Palæontologica Indica,' published under his direction.

Professor Oldham is the author of more than twenty Geological Memoirs and Reports, published in the Journal of the Geological Society of Dublin, that of the Geological Society of London, the Journal of the Asiatic Society of Bengal, the Government Records of the Geological Society of India, and other serial publications.

Among other work, many years ago (in 1843) he discovered the first known fossils in the Cambrian rocks of Brayhead, to which, by the late Professor Edward Forbes, the generic name of *Oldhamia* was given,—a discovery which in its day created the same kind of impression among geologists that the discovery of *Eozoon* produced when found by the late Sir William Logan in the Laurentian rocks of Canada. He was also among the earliest of the workers on the Geology of Ireland to show that above the ice-scratched rocks of the island marine shells were found in clays and gravels up to 600 feet above the level of the sea; and arguing on this discovery, he produced two maps showing the state of Ireland as a group of islands when submerged to that depth, and also when submerged to a depth of 1000 feet, which he considered himself justified in believing to have been the case.

Some of his other memoirs give excellent accounts of the geology of large tracts of India, in one of which he showed that the Rajmahal Hills consist of great lava-flows of trappean rocks, proved to have been ejected as lavas by the fact that the sandstones with which they are interbedded are always much altered by the trap that rests upon them, and unaltered when they lie upon the traps. His memoirs on the Cretaceous rocks of parts of India also conveyed a great deal of new knowledge to European geologists; and the manner in which he has directed the Geological Survey of that great country, from the Himalaya to Cape Comorin (still going on), deserves the gratitude of geologists in particular and of men of science in general.

The Medal was received by Professor Ramsay for Dr. Oldham.

The Statutes relating to the election of Council and Officers were then read, and Colonel Younghusband and Dr. Hector having been, with the consent of the Society, nominated Scrutators, the votes of the Fellows present were collected, and the following were declared duly elected as Council and Officers for the ensuing year:—

President.—Joseph Dalton Hooker, C.B., M.D., D.C.L., LL.D.

Treasurer.—William Spottiswoode, M.A., LL.D.

Secretaries.— { Prof. George Gabriel Stokes, M.A., D.C.L., LL.D.
Prof. Thomas Henry Huxley, LL.D., Ph.D.

Foreign Secretary.—Prof. Alexander William Williamson, Ph.D.

Other Members of the Council.—Professor J. Couch Adams, LL.D.; Major-General John T. Boileau; Edward Viscount Cardwell, F.G.S.; Warren De La Rue, D.C.L.; Captain Frederick J. O. Evans, R.N., C.B.; Edward Frankland, D.C.L.; Albert C. L. G. Günther, M.A., M.D.; Professor T. Wharton Jones, F.R.C.S.; Joseph Norman Lockyer, F.R.A.S.; The Rev. Robert Main, M.A.; Professor Daniel Oliver, F.L.S.; Professor Edmund A. Parkes, M.D.; Right Hon. Lyon Playfair, C.B., LL.D.; William Pole, C.E., Mus. Doc.; The Rev. Bartholomew Price, M.A.; Warington W. Smyth, M.A.

The thanks of the Society were given to the Scrutators.

The following Table shows the progress and present state of the Society with respect to the number of Fellows:—

	Patron and Royal.	Foreign.	Com-pounders.	£4 yearly.	Total.
November 30, 1874.	4	42	266	259	571
Elected		+ 9	+ 5	+ 15	+ 29
Deceased		– 3	– 15	– 15	– 33
Since compounded .			+ 1	– 1	
November 30, 1875.	4	48	257	258	567

Statement of Income and Expenditure during the Year ending November 30, 1875.

	£	s.	d
Annual Contributions	1092	0	0
Admission Fees	200	0	0
Compositions	272	0	0
Rents	324	18	7
Dividends (exclusive of Trust Funds)	1510	16	8
Sale of Transactions, Proceedings, &c.	668	1	7
Admiralty	250	0	0
Repayments	2	19	11
	£4320	16	9
Balances from 1874	274	11	10

	£	s.	d.	£	s.	d.
Salaries and Wages				1201	10	4
Prof. Rupert Jones—for Arctic Manual				100	0	0
The Scientific Catalogue				224	17	6
Books for the Library				254	8	5
Binding ditto				100	0	5
Printing Transactions, Parts II. 1874, Part I. 1875	429	18	9	2012	3	2
Ditto Proceedings, Nos. 156–163	397	11	9			
Ditto Miscellaneous	82	17	6			
Paper for Transactions and Proceedings	247	9	8			
Binding and Stitching ditto	80	11	0			
Engraving and Lithography	773	14	6			
Soirée and Reception Expenses				67	10	7
Miscellaneous Expenses	24	14	1	332	1	8
Coal, Lighting, Soap, &c.	112	5	2			
House Expenses	50	13	9			
Tea Expenses	15	19	11			
Fire Insurance	41	15	0			
Taxes	5	1	10			
Advertising	13	11	6			
Few and Co., Law Charges	22	15	1			
Postage, Parcels, and Petty Charges	36	13	11			
Mablethorpe Schools, Donation	2	2	0			
Subscription and Balance repaid	6	9	5			
				£4292	12	1

Trust Funds.

	£	s.	d.	£	s.	d.
Donation Fund	173	0	8	320	11	4
Rumford Fund	69	2	2			
Wintringham Fund	35	14	0			
Copley Medal Fund	10	0	0			
Davy Medal Fund	32	14	6			
Brought forward from Rumford account, 1872				1	10	0
				£4917	9	11

	£	s.	d.	£	s.	d.
Donation Fund	195	0	0	379	17	10
Rumford Fund	137	12	7			
Wintringham Fund	35	12	6			
Copley Medal Fund	4	13	6			
W. G. Adams, Bakerian Lecture	4	0	0			
Dr. Ferrier, Croonian Lecture	2	19	3			
				4672	9	11
Balance at Bank				220	13	8
Balances on hand, Catalogue and Petty Cash				24	6	4
				£4917	9	11

W. SPOTTISWOODE,
Treasurer.

Estates and Property of the Royal Society, including Trust Funds.

Estate at Mablethorpe, Lincolnshire (55 A. 2 R. 2 P.), £136 per annum.
Estate at Acton, Middlesex (34 A. 2 R. 4¾ P.), £167 17*s.* 10*d.* per annum.
Fee Farm near Lewes, Sussex, rent £19 4*s.* per annum.
One fifth of the clear rent of an estate at Lambeth Hill, from the College of Physicians, £3 per annum.
Stevenson Bequest. Chancery Dividend. One fourth annual interest on £85,336, Government Annuities and Bank Stock (produced £474 17*s.* 8*d.* in 1874–75).
£14,000 Reduced 3 per Cent. Annuities.
£30,161 0*s.* 10*d.* Consolidated Bank Annuities.
£403 9*s.* 8*d.* New 2½ per Cent. Stock—Bakerian and Copley Medal Fund.
£660 Madras Guaranteed 5 per Cent. Railway Stock—Davy Medal Fund.
£10,000 Italian Irrigation Bonds—The Gassiot Trust.

Trust Funds. 1875.

Scientific Relief Fund.

	£	s.	d.
Investments up to July 1872, New 3 per Cent. Annuities	6328	11	2
,, ,, Metropolitan 3½ Consols	100	0	0
	£6428	11	2

Dr.	£	s.	d.	*Cr.*	£	s.	d.
Balance	214	9	0	By Grants	160	0	0
Dividends	191	15	6	Balance	246	4	6
	£406	4	6		£406	4	6

Donation Fund.

£5816 1s. 1d. Consols.

	£	s.	d.		£	s.	d.
To Balance	620	6	4	By Grants	195	0	0
Dividends	173	0	8	Balance	598	7	0
	£793	7	0		£793	7	0

Rumford Fund.

£2332 19*s*. Consols.

	£	*s.*	*d.*		£	*s.*	*d.*
Two years' Dividends, 1874	137	12	7	Gold and Silver for Medals, Engraving, &c.	61	0	2
				J. N. Lockyer. Balance	76	12	5
Dividends, 1875	£69	2	2		£137	12	7

Bakerian and Copley Medal Fund.

£403 9*s*. 8*d*. New 2½ per Cent.

	£	*s.*	*d.*		£	*s.*	*d.*
To Balance	69	5	1	By Gold Medal	4	13	6
Dividends	10	0	0	Bakerian Lecture	4	0	0
				Balance	70	11	7
	£79	5	1		£79	5	1

Wintringham Fund.

£1200 Consols.

	£	*s.*	*d.*		£	*s.*	*d.*
To Balance, 1874	35	12	6	By Payment to Foundling Hospital, 1875	35	12	6
Dividends, 1875	35	14	0				
	£						

GENERAL LIBRARY University of MICHIGAN

Croonian Lecture Fund.

	£	s.	d.		£	s.	d.
To one fifth of Rent of Estate at Lambeth Hill, payable by the College of Physicians	2	19	3	By Croonian Lecture	2	19	3

Davy Medal Fund.

£660 Madras Guaranteed 5 per Cent. Railway Stock.

	£	s.	d.				
To Balance	169	4	2				
Dividends	32	14	6				
	£201	18	8				

The Gassiot Trust.

£10,000 Italian Irrigation Bonds.

	£	s.	d.		£	s.	d.
To Balance	178	10	0	By Payments to Kew Committee	499	19	4
Dividends	499	9	4	Balance	178	10	0
	678	19	4		678	9	4

Account of the appropriation of the sum of £1000 annually voted by Parliament to the Royal Society (the Government Grant), to be employed in aiding the advancement of Science (continued from Vol. XXIII. p. 80).

1875.

1. Mr. C. R. A. Wright, for continuation of Researches on the Opium Alkaloids	£50
2. Mr. G. J. Romanes, for an Experimental Inquiry into the Facts of Heredity, as exhibited by Plants and by Animals	30
3. Messrs. Dewar and M'Kendrick, for an Investigation of the Physiological Action of Light, and of the Chinoline and Pyridine Bases	150
4. Prof. W. C. Williamson, for Researches on the Organization of the Fossil Plants of the Coal-measures	30
5. Prof. Church, for aid in continuing and extending Investigations into the Colouring-matter Turacin	50
6. Prof. G. C. Foster, for Apparatus and Experiments to establish a practical method of measuring the Electrical Resistance of any conductor in absolute electromagnetic measure	100
7. Mr. H. T. Stainton, for aid in publishing the 'Zoological Record'	100
8. Dr. Bigsby, for aid in publishing a 'Thesaurus Devonico-Carboniferus'	150
9. Dr. Maxwell Simpson, for continuation of Researches on the Synthesis of Organic Compounds	50
10. Prof. Roscoe and Prof. Balfour Stewart, for the obtaining of Drawings to scale of a definite Portion of the Solar Spectrum	100
11. G. F. Rodwell, for investigating the change of volume by Heat of Bromide and Chloride of Silver, and of certain Paraffines	60
12. Prof. Duncan, for investigation of the Histology of the Actinidæ, and of the Genus *Primnoa*	25
13. J. N. Lockyer, for continuation of Spectroscopic Researches	200
14. Prof. W. N. Hartley, for continuation of Researches on the Photographic Spectra of Substances	50
15. Prof. W. K. Parker, for aid, in publication by the Linnean Society, of Drawings illustrative of Researches on the Development of the Skull in the Vertebrata	100
16. Mr. J. M. Thomson, for Experiments on the Absorption of Gases by Charcoal at high Pressures	25
17. Mr. F. A. Mahomed, for Researches on Arterial Tension	25
18. Sir W. Thomson, for Reduction of Tidal Observations	100
	£1395

Dr.	£	*s.*	*d.*	*Cr.*	£	*s.*	*d.*
To balance on hand, Nov. 30, 1874	1157	19	7	By Appropriations as above	1395	0	0
To Grant from Treasury (1875)	1000	0	0	Printing and Postal charges	4	5	0
Repayment :— F. Galton	25	0	0	Balance on hand, Nov. 30, 1875	797	7	4
Interest	13	12	9				
	£2196	12	4		£2196	12	4

Account of Grants from the Donation Fund in 1874–75.

Prof. Rupert Jones, to enable him to prepare illustrations of his investigations on Fossil Entomostraca	25	0	0
Mr. H. Willett, in aid of the Sub-Wealden Exploration Fund	50	0	0
Dr. Carpenter, for payment of Assistant-Naturalist in the Cruise of the 'Valorous' and for apparatus	120	0	0
	£195	0	0

Report of the Kew Committee for the Year ending October 31, 1875.

Magnetic Work.—The year has been marked by the recommencement of regular work with the Magnetographs, which had been taken down for examination and repair by Mr. Adie, as described in the last Report. The scale-values having been redetermined, the instruments were set in action on the 1st of January, 1875, and therewith the second series of continuous photographic records of magnetic phenomena was inaugurated.

The monthly observations with the absolute instruments have been continued, as usual, by Mr. G. M. Whipple, who also takes charge of the general magnetic work, in which he has had the assistance of Mr. Cullum and F. Figg. The two Sergeants of the Royal Artillery, formerly in Sir E. Sabine's office at Woolwich, have been in regular attendance at Kew throughout the year.

The principal constants employed in the computations for the Tables used in the reduction of the monthly absolute observations which had been determined by Mr. Welsh have been re-examined. A memorandum containing the results of the observations in question for the twelve months ending Sept. 30, 1875, has been prepared, and is appended to this Report; and it is the intention of the Committee to furnish similar statistics with each of their subsequent Reports.

A paper embodying the results of absolute determinations for the six years ending with March 1875 has been prepared and submitted to the Society; it forms a continuation of the similar paper for the preceding six years, ending March 1869, which was submitted by Dr. B. Stewart, and is printed in the 'Proceedings of the Society,' vol. xviii.

The Magnetic Reductions for the current year have been kept up nearly to date. As regards the arrears of work shown in the tabular statement appended to the Report of the Kew Committee of the British Association for 1870–71, no progress had been made in dealing with any of the elements (with the exception of the tabulation of the Declination curves) up to the month of April last, owing to the insufficiency of the regular staff to deal with such a mass of materials; at that period, however, an extra assistant was engaged to undertake the reduction of these arrears. By this means good progress has been made with the first portion of this work, the preparation of the "fair" and "subsidiary" tabulations for the years 1871–1873.

Magnetic data have been supplied to Sir W. Thomson, LL.D., Dr. Atkinson, Capt. Ettrick Creak, R.N., Mr. Woodward, and Mr. H. A. Rowland.

The Unifilar and Dip-circle lent to the Rev. S. J. Perry for use at Kerguelen Island on the Transit-of-Venus Expedition, as mentioned in last Report, have been returned by that gentleman. A Unifilar lent from Kew, in the year 1869, to Capt. Elagin, Imperial Russian Navy, was returned by him in February of this year, and at his request the constants were redetermined and the results forwarded to him. He has left a Dip-circle at Kew to be repaired.

Meteorological Work.—The several self-recording instruments for the continuous registration respectively of Pressure, Temperature, Humidity, Wind (Direction and Velocity), and Rain have been maintained in regular operation as usual under the care of Mr. T. W. Baker, assisted by T. Gunter. The daily standard eye-observations for the control of the automatic records have been made regularly.

In addition to the regular work of Kew as one of the self-recording Observatories in connexion with the Meteorological Office, the duty of examining and checking the work of all the seven Observatories of the same character has been carried on, in accordance with the method described in the Report of the British Association for 1869. This portion of the work has been performed by Messrs. Cullum, Hawkesworth, and Deane. In the month of August application was made to the Observatory by the Meteorological Office for the services of one of the staff to take temporary charge of the Valencia Observatory, owing to the serious illness of the Superintendent of that Station, the Rev. Thomas Kerr, who has since died. Mr. Cullum at once consented to undertake the duty, and he has remained at Valencia up to the present time. This change has necessarily weakened the working power of Kew in the special department now under consideration; and in consequence a certain amount of arrears have accumulated, but these will be ere long cleared off.

The only change as regards the photographic instruments has been the substitution of copper chimneys for the gas-jets for the glass chimneys formerly in use, an alteration which has proved to be beneficial.

The result of a careful comparison of the thermogram tabulations at the several observatories, obtained by the use of the fiducial lines traced on the curves by photography, with the standard readings, has shown that the original glass scales supplied (the values for which had been determined at Kew in 1868) were not in all instances sufficiently exact, and new scales have accordingly been supplied where requisite.

Electrometer.—The Self-recording Electrometer continues in operation. Some imperfection, of which the cause was not clearly ascertained, interrupted the continuity of the action of the instrument in August; but this was overcome and the record resumed. Experiments for obtaining the scale-value have been made by the use of a battery of 100 Bunsen's cells.

Mr. Ellis, Superintendent of the Meteorological and Magnetic Department at the Royal Observatory, Greenwich, has visited Kew, by direction of the Astronomer Royal, in order to examine the instrument, in the view of the possible procuring of a similar apparatus for Greenwich.

Photoheliograph.—The instrument which, in February 1873, was transferred to Greenwich for the use of the Astronomer Royal has been reported by him to be ready for immediate return to Kew.

The re-examination of the measurements of the Kew sun-pictures, as noticed in the last Report, has been steadily carried on throughout the year (at the expense of Mr. De La Rue, D.C.L.) by Mr. Whipple, assisted by Mr. M'Laughlin, who has been temporarily engaged for this purpose.

The eye-observations of the sun, after the method of Hofrath Schwabe, have been made daily by Mr. Foster, when possible, as described in the Report for 1872, in order, for the present, to maintain the continuity of the Kew record of sun-spots.

Extra Observations.—The experiments with a Photometer for measuring the total intensity of daylight, which has been designed by Prof. H. E. Roscoe, Ph.D., have been continued during the year, as mentioned in last Report. The original instrument provided by Prof. Roscoe having proved defective, it was replaced by another, which remains on trial.

The observations with Thermometers at different levels on the Pagoda in Kew Gardens were resumed in November 1874, after an interval of a few months, and were continued until March, when the experiments were concluded, having lasted over nearly two years. The results have been sent to the Meteorological Office, at the expense of which Department the investigation was conducted.

A commencement has been made of the observation of Solar Radiation at Kew; and Thermometers for that purpose ("Black bulbs *in vacuo*," by different makers) have been placed in the grounds and read regularly.

The Registering Sundial invented by Mr. J. F. Campbell, F.G.S., which has been in operation for several years at the Office of the Local Government Board, 8 Richmond Terrace, Whitehall, has been transferred to Kew, and is in action at the Observatory. It consists of a glass sphere and wooden bowl, and the effect is measured by the amount of wood charred by the sun's action in the course of six months. Experiments are in progress to obtain a satisfactory daily record of the duration of the sun's heating-action by a similar method.

Verifications.—This department of the Observatory continues to exhibit increased activity, and, in more than one respect, important steps have been taken with the view of augmenting its efficiency.

The following magnetic instruments were verified:—

2 Unifilars for the Arctic Expedition.
2 Declinometers for the Arctic Expedition.
2 Barrow's Dip-circles for the Arctic Expedition.
3 Fox's Circles for the Arctic Expedition.
1 Fox's Circle for Staff-Commander Creak.
1 Dip-needle for H.M.S. 'Challenger.'

Constants were determined for 3 Magnets for the Admiralty.

The set of Magnetographs ordered by Capt. C. Pujazon for the Marine Observatory of San Fernando, near Cadiz, have been constructed, and, after verification at Kew, have been forwarded.

A similar set of Magnetographs has been ordered by Dr. Vogel for the new Astrophysical Observatory at Potsdam, near Berlin.

A Unifilar and Dip-circle have been obtained for Padre F. Denza, of the Observatory of Moncalieri, and have been forwarded to him after verification.

The following meteorological instruments have been verified, this portion of the work being entrusted to Mr. T. W. Baker, assisted by Messrs. Foster, Constable, and Welsh:—

Barometers,	Standards	67
,,	Marine and Station	126
		193
Aneroids		21

Thermometers,	ordinary Meteorological	1238
„	Boiling-point Standards	64
„	Mountain	20
„	Clinical	1439
		2761

In addition, 272 Thermometers have been tested at the melting-point of mercury.

The Committee are glad to say that this department of the operations at Kew shows a very satisfactory increase in utility, as is proved by the following statement, showing the fees paid for the verification of Barometers and Thermometers during the three years 1873–75:—

	Barometers.			Thermometers.			Total.		
	£	s.	d.	£	s.	d.	£	s.	d.
1873	72	5	0	110	17	6	183	2	6
1874	55	10	0	157	16	0	213	6	0
1875	88	7	0	214	17	0	303	4	0

The increase has been mainly under the head of instruments received from opticians.

The Committee have it in contemplation to improve the utility of Kew for the verification of instruments by opening an office in London for their receipt, so as to relieve opticians from the trouble of sending the instruments to Kew and fetching them back again.

13 Standard Thermometers have been calibrated and divided at Kew.

The following is the list of miscellaneous instruments which have been verified:—

Hydrometers	150
Rain-gauges	3
Dial Anemometers (Robinson's)	6

A Thermograph has been tested and its scale-values determined for the Mauritius Observatory.

A double box Sextant, together with a Transit-Theodolite, has been obtained, verified, and forwarded to Major Knight in India.

The apparatus devised by Mr. F. Galton for facilitating the verification of Thermometers, which was mentioned in the last Report, has been erected at Kew, and has been found of great service, especially in the way of affording means of maintaining high temperatures for a considerable length of time.

A number of tubes of exceptional range, for the construction of Standard Thermometers, have been added to those at present in stock.

With reference to the testing of Anemometers, as mentioned in last Report, with the hope that the experiments with artificial rotation would be resumed on a future occasion, it has been found that the large expense which would be entailed to provide a suitable apparatus for use at Kew would exceed the resources of the Observatory. These investigations have therefore not been carried out hitherto.

It has appeared desirable to replace the Cathetometer used in connexion with the Standard Barometer by a new instrument; and accordingly such an apparatus is in process of construction. As soon as this is completed it is intended to institute a comparison between the Standard Barometers at Kew and Greenwich, the Astronomer Royal having most readily consented to such an operation.

Information on meteorological results has been supplied to Mr. G. J. Symons, the Secretary of the Northern Institute of Mining Engineers, Mr. K. J. Marks, and the Editor of the 'Illustrated London News.'

Pendulum Apparatus.—In the use made of the Kew pendulum vacuum-chamber by Capt. Heaviside, R.E., in the course of the year 1874, it was found that a certain amount of deterioration in the joints had taken place. These have since been newly ground and rendered air-tight so as to be ready for use.

Mr. C. J. Peirce, of the United States Coast Survey, having made through the Admiralty an application to the Royal Society to be allowed to swing his pendulums at Kew, has at once received permission, and the experiments will be undertaken in the course of the ensuing year.

Two Iron Tripods, which had been formerly used for swinging invariable pendulums, and had remained in store at Kew, were granted by the Committee to the Hydrographer for the service of the Arctic Expedition. They were repaired at the expense of the Admiralty; and while one of them still remains at Kew, the other has been supplied to the Expedition, together with the wooden clock-supports; at the same time an Astronomical Clock (Shelton, No. 35) was also supplied to the Hydrographic Office.

Chronometer Testing.—It has been under deliberation during the year whether or not it would be advisable to institute at Kew an Office for the testing and rating of Chronometers, of a similar character to that conducted at Bidston Observatory by Mr. J. Hartnup.

The President and Council of the British Horological Institute have expressed themselves favourably to the proposal in a scientific point of view; but as yet no decision has been arrived at by the Committee.

Instruction given.—Four Officers from the Arctic Expedition attended at Kew for instruction in the use of Magnetic instruments, and two others for instruction in the swinging of pendulums and in the use of the Transit-Instrument. The final observations of these gentlemen were recorded for making Kew a base station. Certain modifications in the absolute Magnetic instruments, designed by Mr. Whipple for adaptation for use in high latitudes, have been effected to the satisfaction of the Hydrographer.

Lieut. Wille, of the Norwegian Navy, received instruction in the use of Magnetic instruments.

Mr. H. F. Blanford, Meteorological Reporter to the Government of India, received instruction in the general working of Meteorological instruments, Mr. Northcote in the use of Astronomical, and the Rev. Charles J. Taylor in the use of Meteorological instruments.

Waxed paper has been supplied to

The Radcliffe Observatory.
Zi-ka-Wei, China.
Vienna.
San Fernando.
The Mauritius.
Bombay Observatory.
Armagh.
The Meteorological Office.

A collection of apparatus, principally electrical, which had belonged to the late Sir Francis Ronalds, and had remained in store at Kew from the time of his resigning the superintendence of the Observatory, was most kindly presented to the Committee by his executors in the month of April.

The several pieces of Mechanical Apparatus, such as the Whitworth Lathe and Planing-Machine, procured by Grants from either the Government-Grant Fund or the Donation-Fund, for the use of the Kew Observatory, have been kept in thorough order; and many of them are in constant and others in occasional use at the Observatory.

Library.—The usual Donations of Scientific Periodicals, both English and Foreign, have been received at Kew.

Observatory and Grounds.—H.M. Commissioners of Woods and Forests have supplied a Stove for erection in the Verification Room.

Application has been made to the same Office for the formation of a gravelled footway across the Old Deer Park to the Observatory, and for certain internal repairs to the Building.

The detached houses within the Observatory-enclosure, used respectively for Magnetic Observations, workshop, and store-house, have been thoroughly cleaned and painted.

Staff.—The Staff employed at Kew are as follows:—Mr. Samuel Jeffery, Superintendent; G. M. Whipple, B.Sc., First Assistant; T. W. Baker, Second Assistant; J. E. Cullum, J. W. Hawkesworth, J. Foster, F. Figg, A. B. Deane, E. Constable, G. A. Henniker, T. Gunter, and P. Welch.

Mr. Robert H. Scott continues to act as Honorary Secretary to the Committee.

Visitors.—The Observatory has been honoured by the presence, among others, of:—

Prof. J. C. Adams, LL.D., of Cambridge.
Dr. C. Borgen, Marine Observatory, Wilhelmshaven.
Señor Da Souza, of Coimbra.

Dr. Adolph Hirsch, Neufchâtel.
British Horological Institute, a Deputation from.
Capt. Hoffmann, Wilhelmshaven.
Prof. H. M'Leod, F.C.S., and the Students of the Royal Indian C.E. Coll., Cooper's Hill.
M. Redier, Paris.
Dr. Ruhlmann, of Hanover.
Mr. H. C. Russell, of Sydney.
Prof. Sporer, of Anclam.
Dr. H. Vogel, Sonnenwarte, Potsdam.

The following is the Balance Sheet of the Observatory for the year; and it will be seen from it that the finances are in a fairly satisfactory condition :—

Abstract. *Kew Observatory Revenue and Expenditure Account from November 1, 1874, to October 31, 1875.*

Dr. RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance from 1873–74				548	17	6
Royal Society (Gassiot Trust)	£249	19	8			
„ „	249	19	8			
				499	19	4
Meteorological Committee Allowances	162	10	0			
„ „ „	162	10	0			
„ „ „	162	10	0			
„ „ „	162	10	0			
				650	0	0
Meteorological Committee, for Postages &c.	12	4	1			
„ „ Pagoda Observations	9	9	0			
Royal Society Government Grant for Anemometer Experiments per Mr. Scott	16	14	9			
				38	7	10
Payment for Instruments by Commission				251	3	9
Sale of Waxed Paper				87	16	3
Verification Fees, Magnetic Instruments	58	4	0			
„ „ Met. Com., B. T. Inst.	29	16	0			
„ „ —— Admiralty	27	14	0			
„ „ Opticians &c.	252	13	6			
Sale of Standard Thermometers	25	7	6			
Instruction Fees &c.	61	17	0			
Payments for Copying Registers	0	10	0			
				456	2	0
Mr. De La Rue for Sun-work				100	0	0
Prof. Roscoe for Photometer Experiments	7	13	9			
Sale of Photographic Residues	2	5	2			
				9	18	11
				£2642	5	7

EXPENDITURE. *Cr.*

	£	s.	d.	£	s.	d.
By Salaries and extra work				1063	8	9
Rent of Land	£15	2	6			
Fuel and Gas	92	2	2			
Furniture and Fittings	22	1	7			
Chandlery &c.	11	13	3			
Painting and Repairs	21	0	7			
				162	0	1
Printing and Stationery	18	14	4			
Postages	8	12	5			
Messenger and Housekeeper	49	19	4			
Porterage and Contingencies	32	16	5			
				110	2	6
Instruments purchased on Commission				271	1	9
Postages and Payments on behalf of Meteorological Committee	20	0	1			
Pagoda Observations	8	5	0			
Anemometer Experiments on behalf of Mr. Scott	0	15	0			
				29	0	1
Purchase of Waxed Paper, Packing, &c.				69	5	3
Chemicals	33	18	10			
Thermometers	99	0	0			
Ice and Carbonic-Acid Gas	9	16	2			
Anemograph Sheets	2	3	9			
Repair of Instruments and Purchase of New ditto	76	14	0			
Carpenters' Work and Sundries	7	6	10			
				228	19	7
Sun-work expenses				109	13	0
Pendulum Experiment Expenses				4	5	9
Roscoe's Photometer Experiment Expenses				8	18	7
London and Westminster Bank	479	0	11			
London and County Bank	90	17	11			
Cash in hand	15	11	5			
Balance				585	10	3
				£2642	5	7

November 13, 1875. Examined, compared with the vouchers, and found correct. (Signed) FRANCIS GALTON, *Auditor*.

ASSETS.

	£	s.	d.
By Balance as per Statement	585	10	3
Verification Fees due	17	16	3
Standard Thermometers sold	10	10	0
„ „ in stock (valued at)	110	16	0
Waxed Paper sold	9	10	0
„ „ in stock	26	5	0
Meteorological Committee Sundries	8	2	9
Mr. De La Rue for Sun-work	9	13	0
	£778	3	3

LIABILITIES.

	£	s.	d.
To Gas and Fuel	12	16	10
Chemicals	5	10	7
Instruments and Apparatus	14	9	8
Stationery and Printing	4	7	11
Ironmonger	4	6	5
Purchase of San Fernando Magnetographs	75	0	0
Balance	661	11	10

APPENDIX.

Magnetic Observations made at the Kew Observatory, Lat. 51° 28′ 6″ *N., Long.* $0^h\ 1^m\ 15^s{\cdot}1$ *W., for the year October* 1874 *to September* 1875.

The observations of Deflection and Vibration given in the annexed Tables were all made with the Collimator Magnet marked K C1, and the Kew 9-inch Unifilar Magnetometer by Jones, the property of the Magnetic Office, directed by General Sir E. Sabine.

The Declination observations have also been made with the same Magnetometer, Collimator Magnet N E being employed for the purpose.

The Dip observations were made with Dip-circle No. 33, the needles 1 and 2 only being used; these are 3½ inches in length.

The results of the observations of Deflection and Vibration give the values of the Horizontal Force, which, being combined with the Dip observations, furnish the Vertical and Total Forces.

These are expressed in both English and metrical scales—the units in the first being one foot, one second of mean solar time, and one grain; and in the other one millimetre, one second of time, and one milligramme, the factor for reducing the English values to metric values being 0·46108.

The moment of inertia of the magnet with its stirrup was determined in 1858 by the late Mr. Welsh, as were also the coefficients applied in corrections for temperature variations and terrestrial induction.

The value of $\log \pi^2 K$ employed in the reduction is 1·64457 at temperature 60°.

The induction-coefficient μ is 0·000194.

The correction of the magnetic power for temperature t_0 to an adopted standard temperature of 35° Fahr. is

$$0{\cdot}0001194(t_0-35)+0{\cdot}000{,}000{,}213(t_0-35)^2.$$

The true distances between the centres of the deflecting and deflected magnets, when the former is placed at the divisions of the deflection-bar marked 1·0 ft. and 1·3 ft., are 1·000075 ft. and 1·300097 ft. respectively.

The times of vibration given in the Table are each derived from the mean of 12 or 14 observations of the time occupied by the magnet in making 100 vibrations, corrections being applied for the torsion-force of the suspension-thread subsequently.

No corrections have been made for rate of chronometer or arc of vibration, these being always very small.

The value of the constant P, employed in the formula of reduction $\frac{m}{X}=\frac{m'}{X'}\left(1-\frac{P}{r_0^2}\right)$, is $-0{\cdot}00192$.

In each observation of absolute Declination the instrumental readings have been referred to marks made upon the stone obelisk erected about a quarter of a mile north of the Observatory as a meridian mark, the orientation of which, with respect to the Magnetometer, was determined by the late Mr. Welsh, and has since been carefully verified.

The observers' initials refer—W to Mr. G. M. Whipple, C to Mr. J. E. Cullum, P to Mr. C. O. L. Power, and F to Mr. F. G. Figg.

Observations of Deflection for Absolute Measure of Horizontal Force.

Month.	G. M. T.	Distances of Centres of Magnets.	Temperature.	Observed Deflection.	Log $\frac{m}{X}$. Mean.	Observer.
1874.	d h m	foot.	°	° ′ ″		
October	21 12 33 P.M.	1·0	59·7	15 49 41	9·13650	W.
		1·3	......	7 8 23		”
	2 17 ”	1·0	59·8	15 44 4		”
		1·3	......	7 8 14		”
November	27 12 24 P.M.	1·0	36·5	15 53 22	9·13726	W.
		1·3	......	7 10 19		”
	2 14 ”	1·0	39·2	15 52 52		”
		1·3	......	7 9 38		”
December	22 1 7 P.M.	1·0	32·8	15 54 13	9·13647	W.
		1·3	......	7 10 9		”
	2 31 ”	1·0	33·1	15 51 16		”
1875.		1·3	......	7 8 24		”
January	26 11 56 A.M.	1·0	42·6	15 52 7	9·13678	W.
		1·3	......	7 9 11		”
	12 24 P.M.	1·0	43·8	15 51 4		”
		1·3	......	7 8 46		”
February	24 2 8 P.M.	1·0	40·2	15 49 48	9·13602	C.
		1·3	......	7 8 24		”
	2 37 ”	1·0	41·8	15 50 10		”
		1·3	......	7 8 35		”
March	22 12 48 P.M.	1·0	51·6	15 46 45	9·13586	W.
		1·3	......	7 8 3		”
	2 18 ”	1·0	52·3	15 48 38		”
		1·3	......	7 7 22		”
April	26 12 38 P.M.	1·0	62·8	15 48 44	9·13655	C.
		1·3	......	7 7 50		”
	2 8 ”	1·0	65·9	15 47 7		”
		1·3	......	7 6 47		”
May	24 1 40 P.M.	1·0	71·4	15 46 7	9·13620	C.
		1·3	......	7 6 48		”
	2 36 ”	1·0	71·1	15 45 43		”
		1·3	......	7 6 20		”
June	23 12 40 P.M.	1·4	69·5	15 47 46	9·13629	C.
		1·3	......	7 6 46		”
	2 16 ”	1·0	73·8	15 44 55		”
		1·3	......	7 6 10		”
July	28 1 34 P.M.	1·0	74·6	15 46 1	9·13649	C.
		1·3	......	7 8 19		”
	2 38 ”	1·0	75·8	15 43 39		”
		1·3	......	7 5 44		”
August	18 12 21 P.M.	1·0	73·6	15 44 24	9·13549	C.
		1·3	......	7 5 45		”
	2 39 ”	1·0	77·8	15 43 8		”
		1·3	......	7 5 12		”
September	21 12 noon.	1·0	67·4	15 47 25	9·13617	W.
		1·3	......	7 7 8		”
	1 56 P.M.	1·0	69·0	15 44 58		”
		1·3	......	7 6 26		”

Vibration Observations for Absolute Measure of Horizontal Force.

Month.	G. M. T.	Temperature.	Time of one Vibration.	Log *m*X. Mean.	Value of *m*.	Observer.
1874.	d h m	°	secs.			
October	21 11 48 A.M.	57·8	4·6185	0·31512	0·53188	W.
	2 51 P.M.	59·2	4·6191			”
November	27 11 47 A.M.	33·8	4·6098	0·31527	0·53243	”
	2 44 P.M.	39·6	4·6125			”
December	22 12 26 P.M.	30·8	4·6156	0·31438	0 53140	”
	3 20 ”	32·0	4·6148			”
1875.						
January...........	26 11 20 A.M.	41·2	4·6131	0·31548	0·53227	”
	12 50 P.M.	45·0	4·6130			”
February	24 1 20 P.M.	36·9	4·6081	0·31553	0·53183	C.
	4 18 ”	48·6	4·6173			”
March	22 12 24 P.M.	50 7	4·6250	0·31427	0·53096	W.
	2 50 ”	51·8	4·6194			”
April	26 11 46 A.M.	60·8	4·6261	0·31577	0·53230	C.
	2 45 P.M.	68·5	4·6189			”
May	24 1 0 P.M.	71·7	4·6276	0·31540	0·53186	”
	3 8 ”	71·5	4·6253			”
June	23 11 48 A.M.	68·0	4·6291	0·31480	0·53154	”
	3 14 P.M.	73·7	4·6281			”
July	28 11 59 A.M.	73·0	4·6283	0·31485	·0·53170	”
	3 13 P.M.	75·8	4·6305			”
August	18 11 29 A.M.	73·9	4·6293	0·31488	0·53111	”
	3 17 P.M.	77·5	4·6293			”
September.........	21 11 12 A.M.	64·4	4·6280	0·31465	0·53139	W.
	2 21 P.M.	69·2	4·6275			”

Dip observations.					Magnetic Intensity. (Metrical measures in old-faced figures.)		
Month.	G. M. T.	Needle.	Dip.	Observer.	X, or Horizontal Force.	Y, or Vertical Force.	Total Force.
1874.	d h m		° ′				
October...	22 2 27 P.M.	1	67 50·00	W.			
	2 30 ”	2	47·46	”			
”	23 2 28 ”	1	50·06	P.	3·8843	9·5269	10·2881
	3 3 ”	2	48·87	”	1·7910	4·3927	4·7437
	Mean	......	67 49·10				
November	23 2 35 P.M.	1	67 49·24	P.			
	2 36 ”	2	49·68	”			
”	26 2 34 ”	1	51·44	W.	3·8815	9·5275	10·2880
	2 31 ”	2	49·84	”	1·7897	4·3930	4·7436
	Mean	......	67 50·05				
December	23 2 40 P.M.	1	67 53·00	W.			
	2 40 ”	2	48·34	”			
	24 2 40 ”	1	52·06	”	3·8811	9·5065	10·2881
	2 38 ”	2	47·78	”	1·7895	4·3833	4·7438
	Mean.........	......	67 50·30				

Dip observations (*continued*).					Magnetic Intensity (*continued*). (Metrical measures in old-faced figures.)		
Month.	G. M. T.	Needle.	Dip.	Observer.	X, or Horizontal Force.	Y, or Vertical Force.	Total Force.
1875.	d h m		° ′				
January	22 3 10 P.M.	1	67 49·68	P.			
	3 10 „	2	47·56	„			
„	27 0 15 „	1	67 51·06	W.	3·8846	9·5284	10·2899
	0 16 „	2	48·47	„	1·7911	4·3934	4·7445
	Mean.........	......	67 49·19				
February	23 2 49 P.M.	1	67 50·06	W.	3·8882	9·5348	10·2970
	2 35 „	2	47·73	„	1·7928	4·3963	4·7478
	Mean.........	......	67 48·89				
March ...	23 2 19 P.M.	1	67 49·78	W.			
	2 19 „	2	46·75	„	3·8833	9·5179	10·2794
	24 3 36 „	1	[49·88]	F.	1·7905	4·3885	4·7397
	Mean.........	......	67 48·26				
April......	27 2 48 P.M.	1	67 51·12	C.	3·8870	9·5398	10·3015
	2 45 „	2	48·72	„	1·7922	4·3987	4·7499
	Mean.........	......	67 49·92				
May	26 2 41 P.M.	1	67 47·37	C.			
	2 43 „	2	46·81	„			
	27 3 5 „	1	48·34	F.	3·8869	9·5203	10·2830
	3 6 „	2	47·40	„	1·7922	4·3897	4·7413
	Mean.........	......	67 47·48				
June	24 2 36 P.M.	1	67 48·31	C.			
	2 40 „	2	48·03	„			
	25 2 54 „	1	48·37	F.	3·8837	9·5183	10·2802
	2 56 „	2	48·03	„	1·7907	4·3887	4·7400
	Mean.........	......	67 48·18				
July	26 3 17 P.M.	1	67 47·53	F.			
	3 15 „	2	47·22	„			
	29 2 42 „	1	51·31	W.	3·8831	9·5188	10·2804
	2 43 „	2	47·75	„	1·7904	4·3889	4·7401
	Mean.........	......	67 48·45				
August ...	19 2 44 P.M.	1	67 48·00	C.			
	2 45 „	2	47·65	„			
	20 3 4 „	1	50·56	F.	3·8877	9·5291	10·2915
	3 6 „	2	47·09	„	1·7926	4·3937	4·7453
	Mean.........	......	67 48·32				
September	20 3 8 P.M.	1	67 49·81	F.			
	3 9 „	2	48·68	„			
	23 2 44 „	1	50·94	W.	3·8836	9·5247	10·2861
	2 51 „	2	46·65	„	1·7907	4·3917	4·7427
	Mean.........	......	67 49·02				

Declination Observations.

		Uncorrected.		Corrected for torsion.		Observer.
Month.	G. M. T.	Observation.	Monthly Mean.	Observation.	Monthly Mean.	
1874.	d. h. m.		West.		West.	
October	22 12 27 P.M.	19° 45′ 20″		19° 50′ 1″		W.
	23 12 30 „	19 49 9	19° 47′ 14″	19 49 9	19° 49′ 35″	„
November	25 12 25 P.M.	19 51 39		19 48 0		P.
	26 12 35 „	19 45 49		19 45 49		W.
	28 12 32 „	19 44 35	19 47 21	19 44 35	19 46 8	„
December	23 11 53 A.M.	19 41 46		19 41 46		„
	24 12 noon	19 40 5	19 40 55	19 40 52	19 41 19	„
1875.						
January	25 12 29 P.M.	19 53 9		19 53 9		P.
	26 10 53 A.M.	19 42 40	19 47 54	19 42 40	19 47 54	„
February	25 12 28 P.M.	19 48 13		19 48 13		W.
	26 2 5 „	19 47 45	19 47 59	19 47 45	19 47 59	„
March............	23 12 31 P.M.	19 46 45		19 46 45		W.
	24 12 56 „	19 46 37	19 46 41	19 46 37	19 46 41	„
April	27 12 18 P.M.	19 45 16		19 45 16		C.
	28 10 25 A.M.	19 40 3	19 42 39	19 40 3	19 42 39	„
May	26 12 21 P.M.	19 40 14		19 43 34		„
	27 12 21 „	19 45 20	19 42 47	19 45 20	19 44 27	„
June	24 11 58 A.M.	19 40 56		19 38 22		„
	25 12 9 P.M.	19 41 28	19 41 12	19 41 28	19 39 55	„
July	29 12 36 P.M.	19 39 5		19 36 32		W.
	30 12 25 „	19 43 35	19 41 20	19 41 1	19 38 46	„
August	19 12 20 P.M.	19 40 10	19 40 10	19 42 37	19 42 37	C.
September	23 12 33 P.M.	19 42 23		19 37 55		W.
	24 12 33 „	19 34 31	19 38 27	19 37 43	19 37 49	„

Presents received, November 18, 1875.

Transactions.

Alexandria:—Société Khédiviale de Géographie. Discours prononcé au Caire à la séance d'inauguration le 2 Juin, 1875, par G. Schweinfurth. 8vo. 1875. Statuts. 8vo. 1875. The Society.

Berwickshire Naturalists' Club. Proceedings. Vol. VII. No. 2. 8vo. The Club.

Boston [U.S.]:—American Academy of Arts and Sciences. Vol. X. (New Series, Vol. II.) 8vo. 1875. The Academy.

Boston Society of Natural History. Memoirs. Vol. II. Part 3. No. 3–5; Part 4. No. 1. 4to. 1874–75. Proceedings. Vol. XVI. Part 3, 4; Vol. XVII. Part 1, 2. 8vo. 1874–75. Jeffries Wyman, Memorial Meeting. 8vo. 1874. The Society.

Bristol:—Naturalists' Society. Proceedings. New Series. Vol. I. Part 1, 2. 8vo. 1874–75. Laws. 1875. List of Members &c. The Society.

Transactions (*continued*).

Brussels :—Société Malacologique de Belgique. Annales. Tome I.–VIII. 8vo. *Bruxelles* 1863–73.
The Society (Mons. Jules Colbeau, Secretary).

Cordova :—Academia Nacional de Ciencias Exactas existente en la Universidad. Boletin. Entrega IV. 8vo. *Buenos Aires* 1875.
The Academy.

Dublin :—Royal Irish Academy. Transactions. Vol. XXIV. Antiquities. Part 9. 4to. 1874. Vol. XXV. Science. Part 5–19. 4to. 1874–75. Proceedings. Series 2. Vol. I. No. 1, 9, 10; Vol. II. No. 2, 3, 10. 8vo. 1870–75. The Academy.

Glasgow :—Philosophical Society. Proceedings. Vol. IX. No. 2. 8vo. 1875. The Society.

Kiel :—Universität. Schriften aus dem Jahre 1874. Band XXI. 4to. 1875. The University.

Liége :—Société Géologique de Belgique. Annales. Tome I. 1874. 8vo. 1875. The Society.

Société Royale des Sciences. Mémoires. Deuxième Série. Tome IV. 8vo. *Bruxelles* 1874. The Society.

London :—British Association. Report of the Forty-fourth Meeting, held at Belfast in August 1874. 8vo. 1875. The Association.

Institution of Civil Engineers. Minutes of Proceedings, 1874–75. Vol. XL., XLI. 8vo. 1875. The Institution.

Linnean Society. Transactions. Vol. XXIX. Part 3. Second Series. Botany. Vol. I. Part 1. Zoology. Vol. I. Part 1. 4to. 1875. Journal. Botany. Vol. XIV. No. 80; Vol. XV. No. 81. 8vo. 1875. The Society.

Pathological Society. Transactions. Vol. XXVI. 8vo. 1875.
The Society.

Royal Asiatic Society. Journal. New Series. Vol. II. Part 2. 8vo. 1875. The Society.

Royal Geographical Society. Proceedings. Vol. XIX. No. 6, 7. 8vo. 1875. The Society.

Royal Medical and Chirurgical Society. Medico-Chirurgical Transactions. Vol. LVIII. 8vo. 1875. Proceedings. Vol. VII. No. 8. 8vo. 1875. The Society.

Zoological Society. Transactions. Vol. IX. Part 1–4. 4to. 1875. Proceedings. 1875. Part 1–3. 8vo. Revised List of Vertebrated Animals in the Gardens. Supplement. 8vo. 1875. The Society.

Milan :—Società Italiana di Scienze Naturali. Memorie. Tomo III. No. 1. 4to. *Milano* 1873. Atti. Vol. XVI. fasc. 3, 4; Vol. XVII. fasc. 1–3. 8vo. 1874–75. The Society.

Reale Istituto Lombardo di Scienze e Lettere. Memorie. Sci. Mat. e Nat. Vol. XII. fasc. 6; Vol. XIII. fasc. 1. 4to. Lettere e Sci. Morali. Vol. XII. fasc. 4; Vol. XIII. fasc. 1. 4to. 1873–74.

Transactions (*continued*).

Rendiconti. Serie 2. Vol. V. fasc. 18–20; Vol. VI.; Vol. VII. fasc. 1–16. 8vo. 1872. The Institute.

Paris:—l'École Polytechnique. Journal. Tome XXVII. 4to. 1874. The School.

Pisa:—Società Toscana di Scienze Naturali. Atti. Vol. I. fasc. 1, 2. 8vo. 1875. The Society.

Quebec:—Literary and Historical Society. Transactions. New Series. Part 2. 8vo. 1875. The Society.

Trieste:—Società Adriatica di Scienze Naturali. Bollettino. No. 2–5. 8vo. 1875. The Society.

Watford:—Natural-History Society and Hertfordshire Field-Club. Transactions. Vol. I. Part 1. 8vo. 1875. The Society.

Reports.

Boston [U.S.]:—Peabody Education Fund. Proceedings of the Trustees from their original organization in 1867. Vol. I. 8vo. 1875. The Hon. Robert C. Winthrop.

Cambridge [U.S.]:—Peabody Museum of American Archæology and Ethnology. Annual Reports of the Trustees. 1–8. 8vo. 1868–75. The Hon. Robert C. Winthrop.

Chicago:—Public Library. Annual Reports of the Board of Directors. 1, 2. 8vo. 1873–74. The Library.

Kiel:—Commission zur Untersuchung der deutschen Meere. Jahresbericht für die Jahre 1872, 1873. Jahrgang II., III. folio. *Berlin* 1875. Ergebnisse der Beobachtungsstationen an den deutschen Küsten über die physikalischen Eigenschaften der Ostsee und Nordsee und die Fischerei, 1874. Heft 10–12. Schlussheft. 4to. 1875. The Institution.

Leeds:—Yorkshire College of Science. First Annual Report. 1874–75. 8vo. 1875. The College.

London:—Admiralty. Report on Ocean-soundings and Temperatures, Pacific Ocean, China, and adjacent seas. H.M.S. 'Challenger.' No. 4. folio. 1875. The Admiralty.

British Museum. A Selection from the Miscellaneous Inscriptions of Assyria, by Sir H. C. Rawlinson, assisted by George Smith (Cuneiform Inscriptions, Vol. IV.) folio. *London* 1875. Catalogue of Oriental Coins. Vol. I. 8vo. 1875. The Trustees.

Corporation of London. Catalogue of the Library. 8vo. 1859. Supplements. VI.–XIII. 8vo. 1866–75. The Corporation.

Medical Officer of the Privy Council and Local Government Board. Reports. New Series. No. 1–3. 8vo. 1874. J. Simon, F.R.S.

Meteorological Office. Quarterly Weather Report. 1873, part 4;

Reports (*continued*).

1874, part 1. 4to. 1875. Hourly Readings. January to May 1875. folio. Report of the Meteorological Committee for 1874. 8vo. 1875. Report of the Proceedings of the Conference on Maritime Meteorology held in London, 1874. 8vo. 1875. Instructions in the use of Meteorological Instruments, by R. H. Scott, F.R.S. 8vo. 1875. The Office.

Madrid:—Comision del Mapa geologico de España. Boletin. Tomo I. 8vo. 1874. The Commission.

San Fernando:—Observatorio de Marina. Almanaque Nautico para 1877. 8vo. *Barcelona* 1876. The Observatory.

Toronto:—Magnetic Observatory. Abstracts and Results of Magnetical and Meteorological Observations from 1841 to 1871. 8vo. 1875. The Observatory.

Washington:—Bureau of Navigation. The American Ephemeris and Nautical Almanac for the year 1878. 8vo. 1875. The Bureau.

Armit (R. H.) Light as a Motive Power, a series of Meteorological Essays. Vol. I. 8vo. *London* 1875. The Author.

Carruthers (G. T.) A Letter to the Astronomer Royal, explaining a new theory of the Solar System. 8vo. 1875. The Author.

Chasles (M.), For. Mem. R.S. Aperçu historique sur l'origine et le développement des Méthodes en Géométrie. Seconde Édition. 4to. 1875. The Author.

Codrington (Sir Edward), Memoir of his Life, with selections from his Correspondence, edited by Lady Bourchier. 2 vols. 8vo. *London* 1873. Lady Bourchier.

Darwin (Charles), F.R.S. Insectivorous Plants. 8vo. *London* 1875. The Movements and Habits of Climbing Plants. Second Edition. 8vo. *London* 1875. The Author.

Davis (Capt. J. E.) and P. L. H. Davis. Sun's true bearing on Azimuth Tables, computed for intervals of four minutes between the parallels of Latitude 30° N. and 30° S. inclusive. 8vo. *London* 1875. The Authors.

Elliot (Sir H. M.) The History of India as told by its own Historians, edited and continued by John Dowson. Vol. VI. 8vo. *London* 1875. Lady Elliot.

Guy (W. A.), F.R.S. The Harveian Oration, 1875. 8vo. *London* 1875. The Author.

Jones (T. Rupert), F.R.S. Manual of the Natural History, Geology, and Physics of Greenland and the neighbouring regions, prepared for the use of the Arctic Expedition of 1875. 8vo. *London* 1875. The Admiralty.

Keller (Ferdinand) The Lake-dwellings of Switzerland and other parts of Europe, translated and arranged by J. E. Lee, F.S.A. 8vo. *London* 1866. The Editor.

Klein (E.), F.R.S. The Anatomy of the Lymphatic System.—II. The Lung. 8vo. *London* 1875. The Author.

Lartet (E.) and H. Christy Reliquiæ Aquitanicæ, edited by T. Rupert Jones, F.R.S. Part 17. 4to. *London* 1875. The Executors of the late H. Christy, Esq.

Lasaulx (A. von) Elemente der Petrographie. 8vo. *Bonn* 1875. The Author, by R. Mallet, F.R.S.

Lee (J. E.) Isca Silurum, or an Illustrated Catalogue of the Museum of Antiquities at Caerleon. 8vo. *London* 1862. Supplement. 8vo. 1868. The Author.

Lorin (M.) Aperçu général de l'Hérédité et de ses lois. 8vo. *Paris* 1875. C. Darwin, F.R.S.

Marie (M.) Théorie des Fonctions de Variables Imaginaires. Tome II. 8vo. *Paris* 1875. The Author.

Mueller (Ferdinandus de) Fragmenta Phytographiæ Australiæ. Vol. VII., VIII. 8vo. *Melbourne* 1869–74. The Author.

Rennie (Sir John), Autobiography of. 8vo. *London* 1875. J. C. Rennie, Esq.

Schultze (Fritz) Kant und Darwin: ein Beitrag der Entwicklungslehre. 8vo. *Jena* 1875. C. Darwin, F.R.S.

Taylor (A. S.), F.R.S. On Poisons in relation to Medical Jurisprudence and Medicine. Third Edition. 12mo. *London* 1875. The Author.

Thomas (W. Cave) The Revised Theory of Light.—Section I. The Principles of the Harmony of Colour. 12mo. *London* 1875. The Author.

Watts (H.), F.R.S. A Dictionary of Chemistry. Second Supplement. 8vo. *London* 1875. The Author.

November 25, 1875.

Transactions.

Berlin:—Königliche Akademie der Wissenschaften. Abhandlungen aus dem Jahre 1874. 4to. 1875. Monatsbericht. April, Mai, Juni, Juli, August 1875. 8vo. The Academy.

Danzig:—Naturforschende Gesellschaft. Schriften. Neue Folge. Band III. Heft 3. 8vo. 1874. Another copy, with photographs. The Society.

Falmouth:—Royal Cornwall Polytechnic Society. Forty-second Annual Report. 8vo. 1874. The Society.

Geneva:—Institut National Génevois. Bulletin. Tome XIX. 8vo. *Genève* 1875. The Institute.

Transactions (*continued*).

Geneva:—Société de Physique et d'Histoire Naturelle. Mémoires. Tome XXIV. Partie 1. 4to. 1874–75. The Society.

Göteborg:—Kongl. Vetenskaps och Vitterhets Samhälle Handlingar. Ny Tidsföljd. 13, 14 Häftet. 8vo. 1874. The Society.

Innsbruck:—Ferdinandeum für Tirol und Vorarlberg. Zeitschrift. Dritte Folge. Heft 19. 8vo. 1875. The Institution.

Naturwissenschaftlich-medizinischer Verein. Berichte. Jahrgang V. 1874. 8vo. 1875. The Institution.

Lausanne:—Société Vaudoise des Sciences Naturelles. Bulletin. 2^e Série. Vol. XIII. No. 74. 8vo. 1875. The Society.

Prague:—Königl. Böhmische Gesellschaft der Wissenschaften. Abhandlungen vom Jahre 1874. Sechste Folge. Band VII. 4to. *Prag* 1875. Sitzungsberichte. Jahrgang 1874. 8vo. The Society.

Salem [U.S.]:—Essex Institute. Bulletin. Vol. VI. 8vo. 1874. The Institute.

Vienna:—Geographische Gesellschaft. Mittheilungen. Band XVII. 8vo. *Wien* 1874. The Society.

Wellington:—New-Zealand Institute. Transactions and Proceedings. Vol. VII. 8vo. 1875. The Institute.

Observations.

Dorpat:—Meteorologische Beobachtungen im Jahre 1874, redigirt und bearbeitet von A. v. Oettingen und K. Weihrauch. Jahrgang 9. Band II. Heft 4. 8vo. 1875. The Observatory.

Mannheim:—Grossherzogliche Sternwarte. Astronomische Beobachtungen, angestellt und herausgegeben von E. Schönfeld. Abtheilung II. 4to. *Carlsruhe* 1875. The Observatory.

Prague:—K.K. Sternwarte. Astronomische, magnetische, und meteorologische Beobachtungen im Jahre 1874, herausgegeben von C. Hornstein. Jahrgang XXXV. 4to. *Prag* 1875. The Observatory.

Utrecht:—Koninklijk Nederlandsch Meteorologisch Instituut. Nederlandsch Meteorologisch Jaarboek voor 1874. Jaargang XXVI. 4to. 1875. The Institution.

Buijs-Ballot (—) Les Courants de la Mer et de l'Atmosphère, traduit du Néerlandais par L. Estourgies. 8vo. *Bruges* 1874. The Author.

Ennis (Jacob) The Origin of the Stars and the causes of their motions and their light. 8vo. *London* 1875. The Author.

Hirn (G. A.) Exposition analytique et expérimentale de la Théorie Mécanique de la Chaleur. 3e Édition. Tome I. 8vo. *Paris* 1875.
Théorie analytique élémentaire du Planimètre Amsler. 8vo. *Paris* 1875. The Author.

Krönig (—) Das Dasein Gottes und das Glück der Menschen, materialistisch-erfahrungsphilosophische Studien. 8vo. *Berlin* 1874. The Author.

Marchand (E.) Étude sur la Force Chimique contenue dans la lumière du Soleil, la Mesure de sa puissance et la détermination des climats qu'elle caractérise. 8vo. *Paris* 1875. Pièces justificatives. The Author.

Smee (A. H.) Milk in Health and Disease. 12mo. *London* 1875. The Author.

Stockwell (J. N.) Theory of the Moon's Motion. 8vo. *Philadelphia* 1875. The Author.

Wallich (Dr. G. C.) On the true Nature of the so-called "Bathybius," and its alleged Function in the Nutrition of the Protozoa. 8vo. *London* 1875. The Author.

Map of New South Wales. Mounted. The Proprietors of the 'Sydney Mail.'

December 9, 1875.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The President announced that he had appointed as Vice-Presidents:—

The Treasurer.
Prof. J. C. Adams.
Capt. Evans.
Dr. Günther.
Dr. W. Pole.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On some Electro-magnetic Rotations of Bar-magnets and Conducting-wires on their Axes." By G. Gore, F.R.S. Received August 30, 1874. Revised October 2, 1875.

1. In all the published forms of Ampère's experiment of the electromagnetic rotation of a vertical bar-magnet or conducting-wire upon its

axis by Ampère, Faraday, Sturgeon, and others, the magnet or wire has either been immersed a large portion of its depth in mercury, or its middle part has been connected by a wire with a surrounding annular channel filled with mercury, and the electric current passed into or out of the magnet or wire by means of that liquid, and the mercury has formed an essential part of the arrangement.

2. In different treatises on electro-magnetism, either no explanation or different ones are given of the cause of the rotation of the magnet or wire. The most usual cause assigned is the action of the portion of current in the mercury and the fixed conductor immersed in it upon the current in the rotating wire or magnet; and the correctness of this explanation is proved by the simultaneous movement of the mercury in the opposite direction.

De la Rive, in his Treatise on Electricity (English edition, 1853, vol. i. page 259), very correctly remarks, "It must not be supposed that the phenomenon of rotation is due, as has been erroneously stated, to the action upon the magnet of the portions of the current that traverse it, or that traverse the conducting-wires attached to the magnet and move with it. In fact, how could a solid system be set in motion by a force emanating from a portion of the very system itself, and connected with it in an indissoluble manner? The action can only arise from a part of the current which is independent of the system that moves. This part is the portion of the circuit which is not connected with the magnet that is set in rotation, and which consequently is situated independent of the system in motion. This kind of action has been calculated by M. Ampère in a perfectly rigorous manner."

3. Although the action of the portion of the current in the mercury and the fixed conductor in contact with it upon the movable current in the rotating wire or magnet is a cause of the movement, there are other circumstances which cooperate to produce the rotation, and which are themselves capable, without assistance, of producing it. Wiedemann* and myself† have shown that an electric current passing from one end to the other of a magnetized iron rod or wire having *dissimilar* poles at its two extremities produces torsion of the wire (the two ends of the wire moving of course in opposite directions), and that reversing the direction either of the current or of the magnetic polarity, reverses the direction of the twist. In all published cases of rotation of bar-magnets on their axes by the influence of electric currents, the two ends of the magnet have had *dissimilar* poles. By meditating upon certain facts connected with this subject, I concluded that, by passing a current from one end to the other of a magnetized rod or wire having *similar* poles at its two ends, the magnet would probably rotate; and experiment has demonstrated that conclusion.

---

* "Magnetischen Untersuchungen," Pogg. Ann. 1862, vol. cxvii. p. 193.

† "On Electro-torsion," Phil. Trans. 1874.

4. Upon a thin wooden tube 15 centims. long and 7 millims. bore I wound a cotton-covered copper wire 1·7 millim. diameter from one end of the tube to the middle, then reversed the direction of winding and continued to the other end and back to the middle, again reversed and coiled to the first end of the tube; by which arrangement the passage of a current through the coils produced two similar poles at the ends of the tube, and two others of the opposite kind at the middle.

The tube being now fixed in a vertical position, a straight iron wire 15 centims. long and 1·8 millim. diameter, pointed at its lower end and surmounted by a brass mercury-cup 5 millims. diameter, containing a drop of mercury, was supported entirely within the tube and free to rotate, by a similar cup (surmounting a fixed vertical brass rod), at the lower end of the tube, the upper end of the axial wire being kept in position by a vertical brass rod fixed above the coil and terminated at its lower end by a sharp point of platinum in the mercury-cup.

A current from 6 one-pint Grove's elements arranged as 3 being now passed through the coil, brass rods, and axial wire, the latter rotated rapidly.

With a downward current through the axial wire, and north poles* at the ends of the tube, the upper end of the wire rotated in the same direction as the hands of a watch. Reversing the direction of the current either in the coil or iron rod, reversed of course the direction of motion. The rotation in this case was not due to obliquity of coil-current, because that was neutralized by the second layer of coils; nor to portions of transverse currents proceeding to or from the brass rods, because each of those portions was 10 centims. distant from the ends of the axial wire; nor was it due to the portions of current entering or leaving the coil, because they entered and left at the same part and in parallel directions, and thus neutralized each other's effect. A copper wire substituted for the iron one would not rotate, probably because copper is so little capable of acquiring longitudinal magnetism.

5. To ascertain if the rotation was merely due to an action of the current in the coil upon either the axial current or longitudinal magnetism of the iron, or whether the coil-current simply performed the function of longitudinally magnetizing the axial wire, I took an iron wire 23 centims. long and 2·7 millims. diameter, sharp-pointed at its lower end, soldered to its upper end a double wire of cotton-covered copper, each wire being 1·7 millim. diameter, coiled the double wire upon the axial rod in two layers (so as to enable two *similar* poles to be formed at the extremities of the axis), and terminated the copper wires by a little brass mercury-cup

---

* By a North pole I mean that which points to the South, and by a South one that which seeks the North. Because if we call that end of a magnet the north which is repelled by the south pole of the earth and attracted by the north pole, we call by dissimilar and opposite names two things which are essentially alike, and by similar names two things which are essentially different and opposite.

just above the top end of the vertical iron axis. By supporting this apparatus as the axial wire in the previous experiment, and passing the current, rotation occurred, showing that the chief use at least of the coil-current was to impart longitudinal magnetism to the axial wire, and that the rotation was not simply due to any reaction between the coil and that wire. Reversing the direction of the current did not reverse the direction of rotation. In another experiment similar to this, I formed about 12 centims. in length of the middle part of the axial wire of copper instead of iron, and obtained similar rotation; but as copper is only slightly capable of acquiring longitudinal magnetism from a coil-current surrounding it, a precisely similar apparatus having an axial wire composed entirely of that metal would not rotate.

These experiments and the following ones produce a striking effect in a lecture, because the rotation appears to be produced without reaction of the moving part of the apparatus upon any external or fixed body.

6. To determine whether the longitudinal element of the coil-current obtained by obliquity of winding of the wire might be substituted for the longitudinal current through the magnet, I took an iron wire 13 centims. long and 1·7 millim. diameter, sharp-pointed at its lower end, soldered near to that end one extremity of a cotton-covered copper wire 1·7 millim. in diameter, coiled the latter in one direction to the middle part of the iron wire, then reversed the direction of winding and coiled to the other end of the iron, and terminated the coil by a little brass cup just above the upper end of the iron wire as before. By supporting this apparatus as in the previous experiments, and passing the current, rapid rotation took place, proving that a longitudinal current in the iron itself was not necessary.

7. To ascertain whether the longitudinal element of the current was essential to the motion, I constructed a similar apparatus to the last, but instead of attaching the upper end of the coil wire direct to the brass cup, I continued the copper wire vertically downwards to the bottom of the coil, to neutralize the effect of obliquity of winding; then carried it outwards and upwards in the form of a large rectangle 5 centims. distant from the coil and on to the mercury-cup, as shown in fig. 1. On passing the current rotation occurred freely, showing that the longitudinal current was not essential to the motion. This experiment, and that described in paragraph 4, appears to prove that the rotation is not an effect of any obliquity or spiral arrangement of the axes of the magnetized iron molecules with regard to the axis of the wire, produced by the combined action of the transverse and longitudinal elements of the current in the coil, because the latter element was neutralized, but that it is an effect of the tangential poleless magnetism in the fixed wires above

Fig. 1.

and below upon the longitudinal magnetism of the movable iron axis and its coil.

8. As an electric solenoid, however, possesses in some degree many of the properties of a magnet, its longitudinal magnetism, though feeble, must have operated in some of the previous experiments; and I therefore now tried to obtain rotation of one by the action of vertical currents. Upon a very thin wooden tube 15 centims. long and 12 millims. external diameter I coiled a single stout cotton-covered copper wire from one end to the other, reversing the direction of winding at the middle of the tube, and surmounting the upper end of the wire by a small brass cup containing mercury. The lower end of the wire was sharply pointed, and the coil was supported as in the previous experiment. By passing the current from 6 one-pint Grove's elements arranged as 3, faint signs of rotation were observed.

9. In each of these cases of rotation an upward vertical current entering a lower south pole or leaving an upper one caused the upper end of the rod to rotate in the direction of the hands of a watch, and a downward current entering or leaving a north pole also produced that direction of motion, and reversing the poles in either case reversed the effect.

10. In each of these instances of rotation, without the aid of a current near the middle of the magnet, the coil being so constructed that the current in it could not be reversed without reversing that in the fixed conductors near it, reversing the direction of the current did not reverse that of the rotation, because the two acting influences were reversed together; and therefore each apparatus had its own direction of rotation, either right-handed or left-handed (↶)[*], according to the direction in which its coils were wound. It follows from this that a current the direction of which is alternately reversed will drive the apparatus quite as well as one in one uniform direction.

11. As the rotation was apparently due to the influence of the tangential poleless magnetism of the portions of vertical current in the fixed conductors upon the longitudinal magnetism of the vertical iron axis and its coils, I now endeavoured to increase the effect. For this purpose I substituted for the upper brass rod a fixed coil consisting of one layer of copper wire upon an iron wire axis, but having dissimilar poles at its ends and no poles at its middle part, and placed between it and the lower brass rod a similar right-handed one to that described in paragraph 6 and free to rotate. The opposed poles of the fixed and movable coils were of opposite kinds, *i. e.* north and south. On passing a current from a Noe's thermopile of 96 elements[†] connected as 24, rapid rotation in a right-handed direction occurred. I now substituted for the

---

[*] By a "right-handed" coil, I mean one the upper end of which rotates in the same direction as the hands of a watch.

[†] I have found this apparatus very convenient for such experiments.

lower brass rod another fixed coil, similar to the upper one, but of an opposite direction of polarity, and passed the current again; still more rapid rotation in the same direction took place, and the effect was very striking. In this latter instance two south poles free to move were opposed to two fixed north poles, and in each instance the current was passed upwards. In the second experiment also the longitudinal magnetic influence of each opposed iron axis and coil acted upon the tangential magnetism of the longitudinal element of the end of the copper coil-current opposed to it, and thus both the longitudinal and the tangential magnetism of each of the four opposed ends cooperated to produce a most effective result.

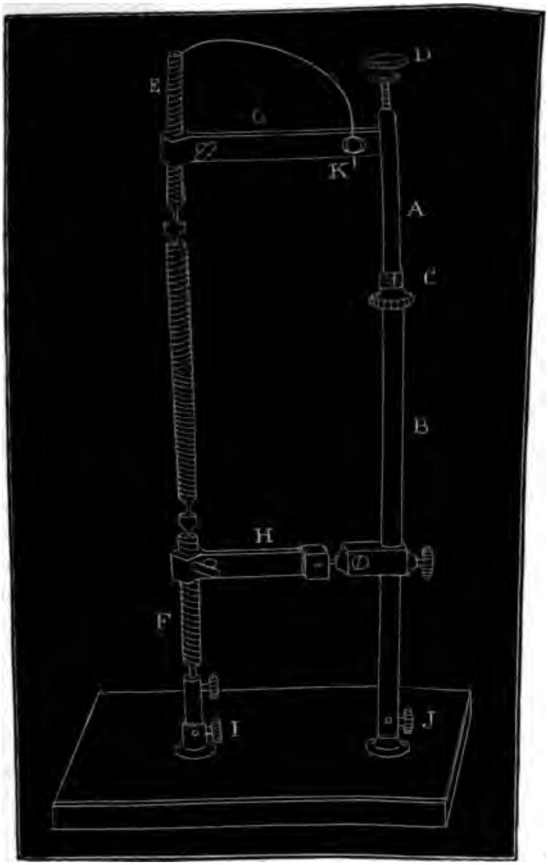
With a thicker axial wire in the moving coil the rotation was not so rapid; and with an axial wire of the usual thickness, but a double layer of copper-wire coils, and the current passing through the axial wire, the rapidity of rotation was not much altered, probably because the increased weight and friction counteracted the effect of the increased magnetism. By substituting for the right-handed movable coil with south poles at its extremities, in these experiments, a left-handed one with north poles at its ends opposed to north poles of the fixed ones, and passing the current, no rotation occurred: in this case the longitudinal element of the current in the movable coil, acting upon the longitudinal magnetism of the fixed iron axis and its coil, tended to produce rotation in one direction, and the longitudinal magnetism of the movable axis and its coil, acting upon the longitudinal element of the current in the fixed coil, tended to produce rotation in the opposite direction.

12. I now substituted for the movable coil a vertical wire of iron 13 centims. long and 1·7 millim. diameter, surmounted by a small brass mercury-cup, passed the current from the thermopile, and obtained rotation, but less rapid than before, probably because of the less degree of longitudinal magnetism; but by enclosing this wire in the axis of a fixed coil which produced appropriate and similar poles at its two ends, as in paragraph 4, and repeating the experiment, very great velocity of rotation was obtained. Rotation of a somewhat thicker wire of nickel was also obtained, both with and without the aid of the current in the middle fixed coil. I also tried, without the aid of the middle fixed coil and with it, a copper wire of similar dimensions to the iron one, and obtained rotation freely: in this case the motion was probably nearly wholly due to the action of the longitudinal magnetism of the adjacent ends of the fixed axial wires and their coils upon the tangential magnetism produced in the movable copper wire by the axial current. Each of these rotations agreed in direction with those of the movable coil.

13. The apparatus represented in fig. 2 was employed for nearly all the various modifications of the experiment, by substituting for one or more of the coils metallic wires &c. as desired. The upper part the brass pillar A was capable of sliding in the lower part B, and

could be fixed by a screw C, which encircled the split end of the tube B. The fine adjustment was effected by means of the screw D, the lower

Fig. 2.



end of which rested upon the top of a tall brass rod inside the brass pillar. The upper and lower fixed coils or rods E and F were insulated from the brass clips G and H, and the battery was attached to the binding-screws I and J. K is a binding-screw for connecting with the upper coil or rod.

14. I also obtained rotation of the iron wire whilst the wire was in a horizontal position, its ends resting in hollows in the ends of the iron axes of the two fixed coils, and the ends of those axes and of the movable wire lying upon the surface of pools of mercury in small watch-glasses. The movable iron wire was enclosed in the axis of a thin iron tube within a fixed coil, having appropriate and similar poles at its ends. The current from the thermopile produced very rapid rotation. This

result proves that the rotations are not due to terrestrial magnetic influence.

15. As the directions of magnetic polarity, electric current, and rotation agree with those in the different forms of Ampère's experiment, and as in most, if not all, of the previously known cases of rotation of a bar-magnet or conducting-wire on its axis an electric current passes through the end of the bar or wire, it is evident that those rotations were due, not only to the portions of current in the mercury and fixed conductors connected with it near the middle of the magnet or wire, but also to the influence of the currents in the fixed conductors near the ends of the magnet or wire.

[*Note added September* 1875.—It having been suggested by Professors Maxwell and Stokes that the rotation in the foregoing experiments was due to the influence of the portions of current in the cups of mercury or in the fixed conductors near the ends of the movable wire or magnet upon the movable magnet, I diminished the internal diameter, both of the upper and lower cups, from 4 millims. to 1·75 millim., and arranged the following apparatus and experiment.

The fixed upper wire was of brass, 2·5 millims. diameter and 60 millims. long; it had no coil upon it, and was used as a conductor only; its lower end terminated in a fine point of a steel needle projecting 6 millims. The lower fixed wire (also used as a conductor only) was of platinum, to resist the action of the mercury; it was 2·3 millims. diameter and 75 millims. long, with a cavity in its upper end 3·5 millims. deep and 1·75 millim. diameter, and containing a thin plate of ruby in its lower part, with a minute hole in the centre for the needle-point to rotate in. The movable wire was 2·5 millims. diameter and 125 millims. long, its upper half being composed of soft iron and its lower half of brass; its lower end terminated in a needle-point like that of the upper fixed wire, and its upper end had a cavity and perforated ruby plate like that in the lower fixed wire. A voltaic coil 60 millims. long and 7 millims. internal diameter, composed of four layers of cotton covered with stout copper wire, was used to magnetize the iron half of the movable wire, and fixed by means of a separate support in a proper vertical position beforehand, so as to enclose in its axis the iron wire portion only. The little cups were also each half filled with a minute globule of mercury before putting the movable wire into its place.

After adjusting the wire so as to make rotation easy, a current from 6 Grove's elements of one-pint capacity arranged as a series of 6, also as a double series of 3, was passed through the coil and vertical wires, and the direction of the portion of the current in the coil alone, also in the vertical wires alone, was varied; but notwithstanding that plenty of current passed, no signs of rotation could be detected. These results, therefore, strongly support the opinion that the rotation in the experiments was due to the action of the portions of the current in the cups of mercury.]

II. "On the Development of *Lepas fascicularis* and the '*Archizoëa*' of Cirripedia." By R. von Willemöes-Suhm, Ph.D., Naturalist to the 'Challenger' Expedition. Communicated by Prof. C. Wyville Thomson, F.R.S. Received September 28, 1875.

(Abstract.)

The materials for this paper were obtained during the 'Challenger's' cruise from Japan to the Sandwich Islands in 35° lat. N., when very curious *Nauplii*, some of them 12 millims. long, were caught, which were identified at once as belonging to the nauplial form to which Dohrn has given the generic name of "*Archizoëa.*" In the daytime these larvæ were scarcer, but at night so common that large bottles could be filled with them. The question (which had been left open by Dohrn) to which cirriped these extraordinary *Nauplii* might belong was solved when large quantities of *Lepas fascicularis* were seen passing the ship for more than a week. It was then possible to keep these barnacles alive and to bring up in our globes such stages of the large *Nauplii* as had also been taken on the surface. Then, again, when catching the surface-animals, free-swimming pupæ were found, which were seen to settle on dead *Velellæ* and assume the form of *Lepas fascicularis*, so that the whole development of this species could be worked out.

Reasons are given why this barnacle belongs to the species *Lepas fascicularis*; and a description is given of some parts of the mouth, which slightly differ from those described by Darwin in the same species.

I. *Development of the egg and of the youngest* Nauplius.

The conclusions to which an investigation into the development of the ovum, and into the changes which occur in it after its formation up to the time when the *Nauplius* comes out, has led are the following:—

1. The youngest eggs, seen in the cæca of the ovarian tubes, are transparent cells with nucleus and nucleolus.

2. The germinal vesicle, as well as the ovum, grows by taking up elements of yelk.

3. All the ova found in the ovary of a barnacle are in the same stage of development. When mature ova are to be seen in the tube, small undeveloped ova may be seen here and there in the cæca, which act very likely as mother cells for further breeding-purposes.

4. The spermatozoa, when fully developed, are simple hair-like filaments.

5. The mature ovum, as contained in the breeding-lamellæ, shows no trace of the vesicula germinalis nor of its nucleolus. Some highly refractive granules may be seen here and there among the yelk-globules. The ovum is oval in form.

6. The segmentation is very irregular, but seems to be complete.

7. As soon as the segmentation begins, large transparent cells are seen separating themselves from the yelk-globules, and increasing in number as the segmentation goes on.

8. These cells form a blastoderm round the yelk. No primitive streak could be seen; but its presence is not denied, as the object is not favourable for these observations.

9. The blastoderm loses its cellular structure and gives way to a granular skin. On both sides of a longitudinal groove three pairs of appendages begin to be visible.

10. The test of the ovum extends as the embryo develops. The latter is very likely still enveloped by a thin blastodermic cuticle, which is clearly visible at the ends of tail and antennæ, when it comes out.

11. The development of the *Nauplius* in the ovum of this *Lepas* shows very much the same stages as those described by Buchholz in *Balanus improvisus*.

II. *The* Nauplius *stages.*

1. The *Nauplius* of *Lepas fascicularis* has, when leaving the egg, a length of 0·35 millim. It moults at least five times, and has before throwing off for the last time the Nauplial appendages a length of 12 millims.

2. The first stage of the *Nauplius* has been seen by Darwin, who describes it, and also by Burmeister.

3. After the first two moults the *Nauplius* gets a large dorsal spine and enters a series of stages, one of which has been described in another *Lepas* by Dohrn as *Archizoëa gigas*.

4. Reasons are given why *Archizoëa gigas* is nearly certain to be the *Nauplius* of *Lepas australis*, a species closely allied to *Lepas fascicularis*, and representing it south of the equator. *Archizoëa gigas* was caught, together with the large *Cyprides* of *Lepas australis*, during the 'Challenger's' antarctic cruise.

5. The tail and the caudal spine of the newly hatched *Nauplius* are pushed in like the tubes of a telescope, and covered by a thin cuticle, which may be the blastodermic one. The same envelops also the lateral horns, but has not been seen at the end of the appendages. The carapax is as yet quite smooth, with the lateral horns hanging down.

6. After the first moult the tail and its spines, which have been pushed out, have a considerable length, and the lateral horns are erected. Only a single pair of small spines is to be seen on the carapax. The glands inside are unicellular.

7. The *Nauplius* after the second moult has, besides the dorsal spine, a series of processes all round the edges of the carapax, to which the unicellular glands send their ducts. Besides the œsophagus, two glands, which formerly were indicated by an agglomeration of cells, become visible. These glands are very likely those which, in the *Cypris* stage,

terminate in the sucker of the antennæ, and are known under the name of cement-glands. Mouth and anus are present. One pair of movable spines on the tail. First "*Archizoëa* stage."

8. Length of *Nauplius* in the fourth stage 6 millims. Three or four movable spines on the tail, with the six of the next stage shining through the chitinous coverings. The glands of the carapax are in connexion with nerves, and present a large network. No nerve-terminations on the lateral horns nor on the feelers. All the processes of the carapax, as well as the lateral horns, have openings at the top for letting out the secretions of the glands.

9. Length of *Nauplius* in the fifth and last stage 12 millims. Six movable spines on the tail.

Large masses of fat are assembling in the carapax, and the *Cypris*-shell is forming underneath it. The first pair of appendages develops inside the antennæ of the *Cypris*, the sucker being formed in the fourth joint, the second of the future antenna. Large compound eyes become visible on both sides of the central eye.

10. The carapax of the *Nauplius* has now a diameter of 2 millims. The appendages are very much like those of *Archizoëa gigas*, in which Dohrn, however, has taken the third pair of appendages for the second, and the second for the third.

11. A specimen of the supposed larva of *Lepas australis* (Dohrn's *Archizoëa gigas*) is figured in the stage just before the metamorphosis into the *Cypris* stage takes place; the two large compound eyes have already developed.

III. *The* Cypris *or pupa stage.*

1. The *Cypris* of the Atlantic, *C. fascicularis*, has been already described by Claus, who has established the homology of its parts with the Copepods.

2. Darwin has described the very large *Cypris* of *Lepas australis* (length 3 millims.), which is in every way similar to that of the present species—a further proof of the probability of the suggestion that Dohrn's large *Nauplii* are the larvæ of that species.

3. Our *Cypris* has a length of 1·3 millim.

4. A description is given of the antennæ with the suckers and their glands, the development of which from the glands in the labrum has been mentioned already. The parts of the mouth (small labrum and three pairs of maxillæ and maxillipeds) and the natatory feet, as well as the caudal appendages with the anus at their base, are figured and described. The organs of sense, the digestive organs, and the shell-gland, which is now very conspicuous, offer scarcely any thing that has not been seen already by Darwin and Claus in the *Cyprides* of the different species of *Lepas*.

IV. *The metamorphosis of the* Cypris *into the young* Lepas.

1. The pupæ are chiefly caught at the very surface of the sea, where they swarm round the dead *Velellæ*, on which they settle. They rarely take to a colony of old barnacles.

2. Soon after settling the new cirri are formed underneath the natatory feet, the head grows out, the eyes are absorbed, and under the *Cypris*-shell the primordial valves of the young *Lepas* appear, which persist during its whole life. The *Cypris*-shell, with the old natatory feet, is then thrown off.

3. The young *Lepas* begins to form the complete shell, and fastens itself more and more by the copious secretions of its glands, which run through the outdrawn and enlarged head into the fixing-antennæ.

4. The cirri of the young *Lepas* develop a larger number of joints, the shell begins to lose its transparency, the body inside turns over a little, as has been described by Darwin, and the young *Lepas* is complete.

Conclusion.

1. As the young stages of the Lepadidæ are pelagic, it is only possible to work out their development at sea, and there at certain seasons. We found only once before the large *Nauplii* of *Lepas australis*. The development of no one of the Lepadidæ has hitherto been known in full; and it seems that even the adult larvæ of our commonest barnacles, such as *L. anatifera* and *L. aserifera*, are as yet unknown.

2. The *Nauplius* stages of *Lepas fascicularis* have not a different morphological value from those of *Balanus* and other genera; therefore there is no reason for giving to this stage a particular name. The term "*Archizoëa*" may remain as a remembrance of Dohrn's interesting discovery, but cannot be applied to the larvæ of other Lepadidæ.

H.M.S. 'Challenger,' Honolulu,
July 28, 1875.

III. "Preliminary Remarks on the Development of some Pelagic Decapods." By R. VON WILLEMÖES-SUHM, Ph.D., Naturalist to the 'Challenger' Expedition. Communicated by Prof. C. WYVILLE THOMSON, F.R.S. Received September 28, 1875.

Since we left Australia I have investigated the metamorphoses of some Crustacea which have been constantly caught by us on the surface of the tropical and subtropical parts of the Pacific. Though these investigations will be continued, I have now arrived at certain results which I think will not be uninteresting to zoologists. The genera to which these remarks refer are *Amphion*, *Sergestes*, and *Leucifer*.

Amphion Reynaudi has been on our lists as an animal "*incertæ sedis*" (Milne-Edwards) for nearly forty years, until Dohrn proved that a full-grown specimen of it, which he dissected, was in possession of branchiæ and of an ovary, therefore no doubt a mature form. He also described one of its young stages, which has the number of appendages of a *Zoëa*, but in which caudal appendages are already developed.

On our voyages in the 'Challenger' we have caught several specimens of *Amphion* and of its larvæ; and I am now able to produce drawings, not only of the *true Zoëa* with a simple telson, but also of all the intermediate stages between it and the adult form with two, three, four, five, and six pairs of walking-legs. Of the full-grown *Amphion* I have examined three specimens, two of which are undoubtedly males, as the testes (and the branchiæ) were plainly visible, the former opening into the last pair of legs.

There is now no doubt that *Amphion* is not a larva, nay, even that there are several species and perhaps genera of this remarkable form. We have caught two very interesting mature animals which are certainly closely allied to *Amphion*. One of these has enormously long eye-stalks, which, having a length of 7 millims., are just as long as the whole animal's body. Another form has got very long eye-stalks too, but is especially remarkable for the antepenultimate joints of its pereiopods, being large paddle-shaped organs, terminated by a very small end-joint. Both have got, like *Amphion*, a central (Nauplial) eye and eight pairs of branched legs; but their body is more *Sergestes*-like and less flat than that of *Amphion*. They certainly belong both to the same genus, and may be called *Amphiones* until more than one specimen of each has been obtained.

To me these Amphionidæ are especially interesting, as I can compare them with the larvæ of *Sergestes* and *Leucifer*, the former of which have also got eight pairs of branched legs and the central eye which persists in the Amphionidæ. There are good reasons for the statement that the larvæ of *Leucifer* and *Sergestes* pass through an *Amphion* stage; and this, it seems to me, throws a good deal of light on the relations and systematical position of *Amphion* itself.

Dohrn, to whom we owe so many fine discoveries concerning the pelagic Crustacea, has described *, under the name of *Elaphocaris*, a small and very spiny *Zoëa* caught in the harbour of Messina. He calls it the larva of a Decapod without fixing its position. This small larva was often seen by me in the Atlantic; but I only lately found out that *Elaphocaris* is the larva of a species, or rather of some species, of *Sergestes*. There is, however, one species of this genus in which the *Zoëa* is not an *Elaphocaris*, but a larger, less spiny form, similar, however, in all other respects to the former. Of the species which develops with an *Elaphocaris* stage in the Western Pacific, I have collected numerous specimens of all the stages, from the youngest Zoëas up to the mature animal. The mode of development is very simple. After the first moulting the larva gets six more branched legs and loses many spines. It enters the *Amphion* stage, then moults, throws the branched legs off, gets branchial, and becomes a young *Sergestes*. Only after this last moulting the central eye, hitherto present, disappears.

---

* V. Siebold und Kölliker, Zeitschrift für wissenschaftliche Zoologie, Band xx. p. 662, tab. 31. fig. 28.

And very similar to that of *Sergestes* is the development of *Leucifer*. Here the earliest *Zoëa* of a species from the Western Pacific has got at first no eyes, then sessile ones come out, and the animal then presents the form which Dana has called *Erichthina demissa*, and which Claus suspected to be not a Stomatopod but a Schizopod larva. After the second moulting this *Erichthina* gets stalked eyes and very long setæ on all its appendages, becoming a rather long, very delicate *Zoëa*. It now enters the *Amphion* stage, but never gets more than four pairs of pereiopods, and loses another pair of these when it moults for the youngest *Leucifer* stage, in which two pairs of pereiopods are absent.

The next question, after having found this out, was, of course, whether *Amphion*, *Sergestes*, and *Leucifer* leave the egg as a *Zoëa*, or whether there is a preceding *Nauplius* stage. My own impression is that in the two first-named genera this is not the case, as the youngest Zoëas which I caught had all the same size, and as none of them was without the large lateral stalked eyes. As for *Leucifer*, the question appears to me to be doubtful; for it is, from what I have seen, quite possible that my youngest *Zoëa*, which has only got a central eye, may be preceded by a *Nauplius*. Of course the simplest thing would be to get the eggs; but there is the difficulty, for *Amphion* is caught very rarely, and has never been obtained at any other time but between 8 and 12 P.M., when it is extremely difficult by lamplight to find out the youngest stages. *Sergestes* larvæ are commoner, appearing also in the daytime, and *Leucifer* is sometimes caught in abundance. I hope, therefore, that I shall succeed in completing my researches about this question, especially as far as the two latter genera are concerned.

H.M.S. 'Challenger,' Honolulu, Sandwich Islands,
July 30, 1875.

December 16, 1875.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Development of the Spinal Nerves in Elasmobranch Fishes." By F. M. Balfour, B.A., F.L.S., Fellow of Trinity College, Cambridge. Communicated by Dr. Michael Foster, F.R.S., Prælector in Physiology in Trinity College, Cambridge. Received October 5, 1875.

(Abstract.)

The author commences by stating that the observations recorded in his paper have been made upon the three following genera of Elasmobranchs —*Scyllium*, *Pristiurus*, and *Torpedo*.

The majority of his observations were made upon specimens procured for him through the agency of the Zoological Station at Naples; but he has also been supplied in a most liberal manner with *Scyllium* embryos by the Directors of the Brighton Aquarium, through the kindness of Mr. Henry Lee. He finds that *Torpedo* embryos are by far more suitable than any other genera he has employed for the investigation of the development of the nerves.

The author then gives a detailed account of his observations upon the development of the spinal nerves in all the genera above mentioned. The following are the chief results at which he has arrived.

The posterior and anterior roots of the spinal nerves arise as independent outgrowths from the involuted epiblast of the neural canal.

The outgrowths for the two roots are at first quite independent of each other, and only unite at a late period of development.

The posterior roots are the first to develop. An outgrowth arises on each side from the dorsal summit of the neural canal, which the author believes to be unbroken throughout its whole length. The outgrowths on the two sides are at first in contact with each other; and from each there springs a series of processes equal in number to the muscle-plates.

These processes are the rudiments of the posterior nerve-roots. They grow ventralwards in contact with the side of the spinal cord.

After the formation of the posterior rudiments, the original outgrowths from the spinal cord cease to be attached to it along its whole length, and remain in connexion with it at a series of points only, each of which corresponds to a posterior root.

The result of these changes is the formation of a series of nerve-roots, each attached to the dorsal summit of the neural canal, and all of them united together dorsally by a continuous commissure, which is the remnant of the primitive outgrowth from the summit of the neural canal.

Subsequently the points of attachment of the posterior roots travel down the sides of the spinal cord, and finally remain fixed at about one third of the distance from its dorsal summit. At the same time the nerve-rudiments undergo histological changes, by which each becomes divided into a root, a ganglion, and a nerve.

At a still later period the nerve given off from the ganglion unites with the anterior nerve-root.

The development of the anterior nerve-roots is far simpler than that of the posterior.

Some little time after the appearance of the posterior roots there spring, on each side, from the ventral corner of the spinal cord, a series of conical outgrowths. These correspond in number with the muscle-plates, and are the rudiments of the anterior roots of the spinal nerves.

These outgrowths are not vertically below the posterior roots, a feature which remains permanent in the adult.

The points of attachment of the anterior roots undergo no change of position like those of the posterior roots; and after they have attained a considerable size they unite with the latter.

The author has also observed that the posterior roots of some and probably of all the cranial nerves develop in the same way as the posterior roots of the spinal nerves, and points out the bearing of this upon the morphological relations between the spinal and cranial nerves.

The remainder of the paper consists of a series of speculations upon the bearing of the above-mentioned facts upon various physiological and morphological problems. These, for the most part, do not admit of being abstracted.

One point the author mentions is the probable homology of the commissure he has detected uniting the dorsal ends of the posterior nerve-roots with the commissure he has described in a previous paper ("A preliminary Account of the Development of the Elasmobranch Fishes," Quart. Journ. of Micros. Science, October 1874, plate 15. fig. 14), which at first unites all the branches of the vagus nerve, and which is subsequently represented by their common junction before uniting with the medulla oblongata.

II. "On the Structure and Development of the Skull in the Batrachia."—Part II. By W. K. Parker, F.R.S. Received October 28, 1875.

(Abstract.)

In the present communication I wish to correct, as much as possible, what now seems to be erroneous in my former account of the Batrachian skull (that of the frog, Phil. Trans. 1871), and also to describe and illustrate the stages in the skulls of three kinds of toads.

Happily for me, Professor Huxley took up this subject at the beginning of last year; and I had frequent opportunities of working, as well as for discussion, with him.

It was soon made plain to me that in my former account of the behaviour of the visceral arches I had been wrong in describing the hyoid arch of the *third stage* as composed of an upper and a lower piece.

The supposed upper piece was merely the outer edge of the arch in front, the mandibular arch; and therefore all reasonings upon the metamorphosis, afterwards, of such a coalesced segment fall to the ground.

Professor Huxley showed me, and my new researches told the same tale, that the hyoid arch does not coalesce at all with the mandibular; that the "columella," whether answering to the "hyomandibular" of a fish or not, has no existence as cartilage, even in young frogs and toads that have taken to land life; afterwards, when they are one third larger, this cartilage appears.

Professor Huxley, and my own observations agree with his, also showed me that the *stapes* is not formed by the separation of a plate of already formed cartilage, but chondrifies later than the auditory sac and much earlier than the columella: in the Urodela it is formed by the segmenting off of a flap of the chondrified capsule. Our mutual researches, after these errors were made evident to me, gradually brought us into greater harmony in our interpretation; and the working out by Professor Huxley of *Menobranchus*, and by myself of others of the Urodela, has been of great service in making clear the meaning of the more complex skull of the Anura.

Being well provided with materials for working at the common toad's skull, and, through the kindness of friends*, for various stages of the two "aglossal" toads, namely *Dactylethra* and *Pipa*, it came to pass that I was in a good position for searching out this subject further, with new light and new material.

Moreover these are not the only types of the Batrachia that have more recently engaged my attention; but the great bull-frog and the paradoxical frog have also had various stages of their skulls laboured at by me. These would have swelled my paper to too great a size; I hope to offer them when the tree-frogs, *Bombinator* toads, and other kinds have been studied.

In this paper I have given, first of all, correcter figures of the nasal labyrinth of the adult frog. Before my former paper was in print I had seen that in the bull-frog the "trabecular cornua" kept their distinctness on the front nasal wall. Professor Huxley has discovered *rhinal processes* in *Rana esculenta* and in *Rana temporaria*. He also showed me a distinct nucleus of cartilage in front of the nasal sac. There are *two* such cartilages on each side, as I soon found, the modified and subdivided "upper labials;" these are shown in the new figures.

By comparison of the skull of the Anura with that of the tailed Amphibia, a better idea can be had of the relations of the mandibular pier with the auditory capsule: newer and more correct names of the attaching processes of the "suspensorium" are here given, in accordance with the nomenclature adopted by Professor Huxley in his memoir on *Menobranchus* (Proc. Zool. Soc. 1874, p. 186).

---

* I am indebted to Professor Huxley for adult skulls of *Dactylethra* and *Pipa*; to Dr. Dobson, F.L.S., of Netley, for another adult *Dactylethra*; to Mr. T. J. Moore, of the Liverpool Free Library and Museum, for four stages of the larval *Dactylethra*; to Dr. Günther, F.R.S., for embryos of *Pipa*; and to Professor W. H. Flower, F.R.S., for ripe young of the same.

For instance, the band which connects the mandibular arch primarily with the trabecular is now called the "pedicle," and the secondary process which binds on the ear-sac is the "otic process." There is no "ascending process" over the orbito-nasal nerve, as in the salamandrian forms; and the apex of the pedicle losing its distinctness, its lower part forms a condyle which articulates with the outer face of the auditory mass below.

The apparent distinctness of this part in the young frog kept up the illusion as to its being a part borrowed from the next arch. It was called by me the "infra-hyomandibular."

The cartilage which I erroneously supposed to be the rudiment of the "columella" lies *over* the portio dura nerve; it was called by me the "supra-hyomandibular." It is in reality the rudiment of the cartilaginous *ear-ring.*

All this, thanks largely to my friend and fellow worker, is made plain now.

In frogs it is not quite easy to recognize the supero-anterior element of the *double* hyoid arch of osseous fishes in the columella; in toads it is easier.

In the frog a small cartilaginous segment is cut off from the proximal end of the shaft of the columella, and lies between it and the stapes. In toads the proximal element is the longer of the two, and is distinguished by being ossified separately, and not by subdivision of the cartilage.

Hence it is not a wild supposition that the proximal shaft-bone may be the "hyomandibular" and the distal the "symplectic," its unossified end being dilated as the "extrastapedial."

In osseous fishes we have this supero-anterior bar in the hyoid region ossified by two centres, but no stapes; in the Urodela the stapes, but, as a rule, no supero-anterior bar; in toads we have both, whilst in frogs the apex of the upper pier is a free nucleus of cartilage.

The primordial cartilaginous skull of the common toad is here worked out, the subjects being tadpoles only one third of an inch in length; their black colour and granular texture made them most difficult objects to interpret, and cost me much anxious labour.

Then in a series of stages comparable with those of the common frog I have traced the metamorphosis of the facial arches, so that the skull of the two common kinds of Batrachia will now be intelligible.

In the tadpole of *Dactylethra* there is much that is new and strange; there are neither suctorial mouth nor horny jaws. The upper labial forms the edge of a broad mouth with an *underhung* lower jaw, the head being extremely depressed, as in certain siluroids and in the frog-fish (*Lophius*).

The labial "tape" coalesces with the trabeculæ, and is continued on each side as a long cartilaginous *string*, which forms the pith of a tentacle which reaches as far as the end of the abdomen.

The branchial orifices are both open *right* and left (not the left only, as in the common kinds), and the fore limbs show their rudiments *outside* the opercular fold.

All the details of this, the flattest and most foliaceous of all chondrocrania described, are of the utmost interest, but cannot be described here.

In this type young toads with four large legs have no trace of a cartilaginous "columella;" and yet in the adult that structure is by far the largest I have yet seen, the "extrastapedial" itself being shaped like a waterlily-leaf, and is relatively of the size of the whole auditory ring of the bull-frog.

This species has only *one* vomer and no bony palatines; its original labial band forms a pair of nasal pouches, and it acquires *four more* pairs of these cartilages above and loses the lower pair.

Dactylethra has the upper element of the "girdle-bone" a "superethmoidal" plate; but the ossification of the chondrocranium itself is not in the ethmoidal but in the sphenoidal region. The huge tympano-Eustachian vaults open by one orifice in the pharynx; its "interhyal" is a ligament attached in the normal position; it has two true *tympanic bones* on each side (like those of certain birds), besides the large cartilaginous *annulus*, and its squamosal and quadrato-jugal are more like those of a tortoise than of an ordinary Batrachian.

Its quadrate bone is ossified, as in Ganoid and Teleostean fishes and tailed Amphibia.

But the Surinam toad (*Pipa monstrosa*) is a rarer creature than even *Dactylethra*, with which it agrees in being *tongueless*.

The embryo is wound like a tape round the large yelk-mass; it has a gaping broad mouth, with neither labial cartilages, nor horny jaws, nor "claspers." It has very small opercula, which do not cover the very early formed limbs: it has gill-arches and branchial vessels; but these are not branched, for there are no gill-tufts or processes that I can discover.

The cartilaginous skull of the embryonic *Pipa* is a very flat leafy structure, like that of the larval *Dactylethra*, but differing from it in many respects. At this stage the *fenestra ovalis* is forming, but there is neither stapes nor columella; at this time there is a large "cerato-hyal" in the usual place for a Batrachian larva, namely articulated to the mandibular pier not far above the condyle of the quadrate.

In ripe young *Pipas* the metamorphosis is complete, although the *shape* of the adult skull is not attained. Ossification is already relatively nearly perfect; three pairs of labials now supplement the deficiencies of the nasal capsule, which is but little chondrified, and in the auditory region the occipital arch and the two auditory capsules are one continuous tract of bone.

The stapes is perfect, and so is the columella with its two shaft-bones in each *stem*; its extrastapedial is like that of *Dactylethra*.

The mandible is perfect, the cerato-hyals *completely gone*, and the branchials are metamorphosed as completely (save that the "thyro-hyals" are not ossified) as in the adults of other Batrachia.

The frontals and parietals have already coalesced; in front there are nasals, preorbitals, and septo-maxillaries, a pair of each; but there is no vomer; there is a pair of styloid *palatine bones*.

The premaxillaries and maxillaries lie entirely on the under or palatine surface; there is no quadrato-jugal.

In the adult the bones are very coarse, fibrous, and with strong ridges and deep excavations, as in certain osseous fishes. There is no "girdle-bone;" the quadrate is now well ossified, and so is Meckel's cartilage, the "articulare" having grafted itself upon the rod.

In neither of these aglossal toads is there a "mento-Meckelian" bone formed at the symphysis.

In the adult *Pipa* the "occipito-otic" masses are stretched far out as large bony arms, on the end of which is the exquisite tympanic apparatus. Both in young and old the superoccipital region is well ossified over as a complete bony arch, and now, in the adult, the occipital condyles look *outwards*; the basioccipital region is a narrow synchondrosial tract.

These are some of the most noteworthy things in *Dactylethra* and in *Pipa*. The common toad shows most important differences from the common frog; but these aglossal types are rich in morphological variation and full of morphological meaning.

The satisfaction accruing to my own mind from the working out of these three (as well as other) types of the Batrachian skull will act as a strong stimulus to keep me a few years longer at the morphology of that group.

As the attachment of the mandibular arch to the skull is complex and very important, I venture to add a few remarks upon it.

On the "Suspensorium" or Pier of the Mandibular Arch in the Amphibia generally.

The Amphibia agree with three groups of fishes (namely, the "Marsipobranchii," the Chimæroids, and the "Dipnoi") in having their suspensorium confluent with the skull.

The simplest form of such a confluence has been shown in the present paper in the early condition of chondrocranium of the common toad, where the apex or dorsal end of the mandibular arch, *during chondrification*, unites with the outer side of the trabecular arch near its dorsal end. Afterwards, in the same type, this confluence is much more complex.

For a longer period in the Urodela the suspensorium is quite separate from the trabecula; as a rule it soon forms *three* attachments; but in this group, as in the Anura, it never unites *by confluence* with the next or hyoid arch.

Each of these groups has its typical method of attaching the suspensorium, and each has types that show remarkable modifications.

In *Menobranchus* and *Rana* (Huxley, *loc. cit.*) we have the two proper types of this structure in the adult.

In the former, the Sauro-batrachian, the apex of the mandibular arch unites with the trabecula near its apex on its outside by a process, the "pedicle," which lies beneath the trigeminal nerve.

A second or "ascending" process mounts over part of that nerve, especially arching over the orbito-nasal and the Vidian branch of the facial nerve, and it unites with the top of the *alisphenoidal crest* of the trabecula.

A third, the "otic process," grows upwards and backwards, and unites with the outside of the auditory capsule; it is pedate, and its thick end runs in front of the ampulla of the horizontal canal.

In the typical adult Batrachian suspensorium the primary union of the apex of the mandibular pier is afterwards lost, this part becoming mere fibrous tissue; but the lower part of the pedicle grows into a thick triangular process of cartilage with its base upwards, and this base becomes the "condyle of the pedicle;" it articulates with the side of the auditory capsule antero-inferiorly. This condyle has its counterpart in some of the Urodela as a swelling of the pedicle near the origin of the otic process below (Huxley, "On *Menobranchus*," plate 29. fig. 2).

In the adult frog the suspensorium is united by a gliding joint to the auditory capsule below, and by fusion of cartilage above and behind.

As far as my observations go, *Siredon* agrees with *Menobranchus*; in *Salamandra* the swelling answering to the "condyle of the pedicle" is very small, and the pedicle is suppressed. In the lowest type also, namely *Proteus anguinus*, the ascending process only is present, and the otic process is small. Some of the Batrachia differ from the frog in having the lower part of the "pedicle" greatly enlarged at first, but very small afterwards, forming a very small condyloid part; whilst the apex is not absorbed, but unites with the auditory capsule. This is seen in *Bufo vulgaris*.

Moreover in that type and in *Dactylethra*, when the legs are well developed, the otic process projects inwards *in front of* the auditory capsule. In *Pseudis paradoxa* this is very distinct as a thick, finger-shaped, free process, which passes inwards as far as the neck of the foremost ampulla.

The last is an instructive condition, as it partly breaks down the fence between the two groups of Amphibia; for in the Urodela the otic process is pedate, the *toe* projecting to nearly the same extent inwards as in *Pseudis*. The term "suspensorium" must not be applied to the part which carries both the mandible and the hyoid arch in most fishes—sharks, rays, ganoids, and teleosteans.

This part, the "hyomandibular," belongs to the second or hyoid arch, and has no representative in most of the Sauro-batrachia, nor in the Batrachia during their larval state.

In *Proteus*, however, contrary to what is seen in the other tailed forms, the proximal hyoid element is as massive as the mandibular pier, its immediate "serial homologue." This "hyomandibular" of *Proteus* is attached by ligament to the suspensorium, the stapes, and the auditory capsule; it is not tilted upwards and forwards like its counterpart in the skate or osseous fish, but agrees with that of the shark in being directly articulated to the cerato-hyal. This, however, does not take place by direct superposition; but the hyomandibular is bevelled largely on its inner face, and overlaps the cerato-hyal. Had it been tilted upwards and forwards it would have applied itself to the outer face of the suspensorium in the manner of the flat fore end of the Batrachian "columella," the *extrastapedial.*

Such a structure occurring in some low-generalized tailless amphibian could only be interpreted as the lump of organic clay out of which the columella had to be fashioned.

Every anomaly in a frog or toad that shows how thin the middle wall of partition is between the two groups will increase to me the probability that the hyomandibular of the *Proteus* is the Batrachian columella "writ large"*.

On signs of Vertebral Segmentation seen in the cephalic part of the Notochord.

In my paper on the skull of the fowl (plate 82. fig. 3. *nc*) I have figured the notochord in the third stage as having *three* partially formed segments. The most distinct of these is the hindermost, and it is ossified. That osseous tract is the homologue of an *early* vertebral "centrum;" and if the other two spindle-shaped regions were to ossify separately there would be three rudimentary cranial centra.

In toads of the first summer (sixth stage of this paper) the shrinking notochord has become submoniliform, as in the chick, but it does not ossify.

In the Salamandrian Amphibia, however, the notochord acquires a bony sheath in front; and in *Seironota perspicillata* larvæ half an inch in length show *two* very well marked cranial centra, the front one with a perfect osseous sheath, whilst the hinder segment has bony grains scattered over the notochordal sheath. This last has the hourglass-shape, and corresponds accurately in form with the rudimentary centrum of the first cervical vertebra.

The dorsal ends of the trabeculæ occupy the apex of the notochord, and

---

* It is *small* in *Spelerpes* and *Desmognathus.*

in these larvæ of *Seironota* the hinder half of the front notochordal segment is not invested by cartilage. But the hinder, feebly ossified segment has a cartilaginous plate on each side, which is already ossifying (as the exoccipital), and these ossifying cartilages are seen to be the accurate counterparts of the "neurapophyses" of the first cervical vertebra.

Afterwards these cartilages grow forward and coalesce with the dorsal ends of the trabeculæ.

These facts are in perfect harmony with what I have been asserting for some years past, namely, that the basioccipital is not the hindermost centrum of a series of cranial vertebræ, but a single bone in the place of a series, the distinctness of which supposed series is lost, their segmentation being suppressed. The modified anterior end of the vertebral column forms the occipital arch. There are no developed cranial vertebræ in front of the "epencephalic," which used to figure as the hindermost of *four*.

III. "Preliminary Observations on the Locomotor System of Medusæ." By G. J. Romanes, M.A., F.L.S. Communicated by Prof. Huxley, Sec.R.S. Received November 1, 1875.

(Abstract.)

I. *Movements of the Medusæ.*

The movements of some of the Medusæ (e.g. *Sarsia*) appear to be as *voluntary* as are those of insects. Some of the discophorous species of naked-eyed Medusæ*, when threatened with injury, manifest peculiar movements, which are quite distinct from the ordinary locomotor contractions. These movements consist in a very strong and protracted systole, followed by a slow and gradual diastole. This spasm-like series of movements is never performed by any Medusa except when the animal is being injured or threatened with injury.

II. *Fundamental Observations.*

§ 1. In the case of all the naked-eyed Medusæ which I have this year been able to procure (viz. thirteen species belonging to six of the most divergent genera) I find it to be true that excision of the extreme periphery of a nectocalyx is followed by immediate, total, and permanent paralysis of the entire organ. The severed margin, on the other hand, continues its rhythmical contractions as vigorously as when it was still *in situ*, and this for many hours after the operation. Among hundreds of observations I have only met with one exception to the otherwise uniform result of this operation. The exception occurred in an individual belonging to the species *Staurophora laciniata*.

---

* I adhere to Forbes's classification only because I have not happened to meet with any individuals of the family Lucernariadæ.

§ 2. In the case of the covered-eyed Medusæ I have not found the result of the operation just mentioned to be so uniform as it is in the case of the naked-eyed Medusæ. Nevertheless this result, although varying greatly in different species and in different individuals of the same species, is, upon the whole, analogous to that which is so remarkable in the case of the naked-eyed Medusæ; that is to say, in the majority of instances excision of the margin of a gonocalyx is followed by a paralysis as immediate and total as is the paralysis similarly caused in a nectocalyx; but the two cases differ in that (*a*) this is far from being *invariably* the case, and (*b*) the paralysis of a gonocalyx, even when total for a time, is seldom *permanent*. After periods varying from a few seconds to half an hour or more occasional contractions begin to take place, or the contractions may be resumed with but little change in their character and frequency.

These remarks apply to gonocalyces in general; but they do not apply in equal degrees to all the genera of covered-eyed Medusæ: *i. e.* different genera of covered-eyed Medusæ manifest, in their constituent individuals, different average degrees of paralysis when subjected to the operation we are considering. Of all the species I have come across, *Aurelia aurita* most resembles the naked-eyed Medusæ in the degree to which the locomotor centres are aggregated in the margin of the swimming-organ; for in the case of this species it frequently happens that the paralysis caused by excision of the margin is permanent.

§ 3. In the genus *Sarsia* I find that excision of the eye-specks alone causes a greater degree of paralysis than does excision of the intermediate portions of the margin alone; for while the former operation is usually sufficient to cause temporary and sometimes permanent paralysis, the latter operation never causes either. That all parts of the marginal tissue between the eye-specks, however, are capable of originating impulses to contraction, is proved by the fact that the smallest atom of this tissue, when left *in situ* after all the rest of the margin has been removed, is frequently sufficient to animate the entire nectocalyx.

§ 4. In the covered-eyed Medusæ I find that the concentration of the marginal supply of locomotor centres into the marginal bodies is even more decided than it is in the case of *Sarsia*. Indeed I have no evidence to show that any part of the margin of a gonocalyx, other than the eight lithocysts, has any function of spontaneity to perform; so that all the remarks made in § 2, while stating the effects of removing the entire margin of gonocalyces, are equally applicable to the effects of removing the lithocysts alone. I may add that in the case of *Aurelia aurita*, which from its flattened shape admits of the fairest experiments being made in this connexion, all the spontaneity of the margin, and so in many cases of the entire animal, is without question seated exclusively in the lithocysts[*].

---

[*] In no case, either among the naked- or the covered-eyed Medusæ, is the polypite affected by removal of the periphery of the swimming-organs.

III. *Stimulation.*

§ 1. All the tissues of all the Medusæ are keenly sensitive to all kinds of stimulation. When a swimming-organ is paralyzed by the operation above described, it invariably responds to a single stimulation by once performing that movement which it would have performed in response to that stimulation had it still been in an unmutilated state.

§ 2. (*a*) To electrical stimulation, both of the direct and of the induced current, the severed margins and the swimming-organs from which they have just been removed are responsive. There is an important difference, however, between the two cases, in that while the severed margins continue responsive to induction-shocks after they have ceased to be affected by make and break of the direct current, the reverse is true of the mutilated swimming-organs—these continuing responsive to make and break of the direct current after they have ceased to be affected by strong induction-shocks, or even by Faradaic electricity with the secondary coil pushed to zero (one cell).

(*b*) By means of a DuBois-Reymond induction-apparatus and of needle-point terminals (the needle being passed through a small piece of cork as a support, and the cork being fixed to stage-forceps on the mechanical stage of a Ross microscope), I was able to investigate the distribution of excitable tracts in *Sarsia.* I found that there is an uninterrupted increase of excitability from the apex to the base of the nectocalyx, that the positions occupied by the radial tubes are tracts of comparatively high excitability, that the eye-specks are the most excitable portions of the margin, and that of the eye-specks the vesicular half is more excitable than is the pigment half.

(*c*) When the marginal rim of any Medusa is removed in a continuous piece, with the exception of one small part, the result, of course, is a long strip of marginal tissue, which is free at all points save at the end which is left attached *in situ.* Upon now irritating the distal end of this marginal strip, a wave of contraction may invariably be seen to start from the point at which the irritation is applied, and with some rapidity to traverse the entire strip. When this contractile wave arrives at the proximal or attached end of the strip, it delivers its influence into the swimming-organ, which thereupon contracts in exactly the same manner as it does when itself directly irritated. Of course spontaneous contractions are always originating in some portion or other of the severed strip; and these give rise to contractile waves and to contractions of the swimming-organ just in the same way as do the disturbances originated by stimuli. In such of the discophorous species of naked-eyed Medusæ, however, as respond to stimulation by the peculiar spasmodic movements of the nectocalyx already described, the difference between the effects upon the nectocalyx of contractile waves which originate in the severed strip spontaneously, and those which there originate in answer to stimulation, is of a very marked character; for the spasmodic movements of the nectocalyx are as easily and as certainly excited by irritating any part of the severed strip as they are by irritating the substance of the nectocalyx itself.

From this description it will readily be seen that a Medusa, when thus operated upon, supplies all the conditions required for conducting experiments in electrotonus: the animal in this form is, for all practical purposes, a nerve-muscle preparation. Accordingly I have spent a great deal of labour over this part of my subject, but with no very satisfactory results. In the case of *Staurophora laciniata*, however, I have sometimes obtained decided indications of kathelectrotonus, but never any of anelectrotonus. I cannot yet speak decidedly with respect to Pflüger's law.

(*d*). *α*. The excitable tissues of Medusæ, although somewhat capricious in the comparative sensitiveness they show to make and break of the current, upon the whole conform to the rules which are followed by the excitable tissues of other animals.

β. Different species of Medusæ manifest differences in the degree of their sensitiveness to electrical stimulation. In all cases, however, the degree of sensitiveness is wonderfully high.

γ. When the constant current is passing in a portion of a strip of a severed margin, the nectocalyx sometimes manifests uneasy motions *during the time the current is passing*; this, however, is perhaps due to variations in the intensity of the current.

δ. When the intrapolar portion of the severed margin of *S. laciniata* happens to be *spontaneously* contracting prior to the passage of the constant current, the moment this current is thrown in such spontaneous contractions usually cease, and are seldom resumed until the current is again broken, when they are almost sure to recommence. This inhibitory effect may be produced a great number of times in succession.

ε. *Exhaustion* of the excitable tissues may be easily shown by the ordinary methods. Exhausted tissue is much less sensitive to stimulation than is fresh tissue, and, so far as the eye can judge, the contractions are slower with the period of latent stimulation prolonged.

ζ. *Tetanus* produced by Faradaic electricity is not of the nature of an apparently single prolonged contraction (except, of course, such of the naked-eyed Medusæ as respond to all kinds of stimuli in this way), but that of a number of contractions rapidly succeeding one another. There is hence no appearance of *summation*.

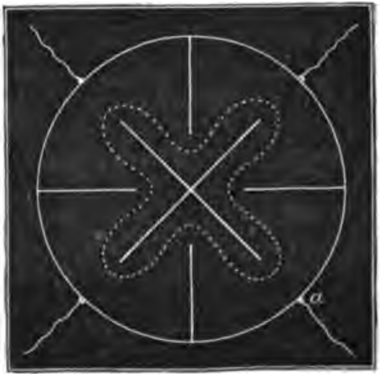
η. When the swimming-bell of *Sarsia* has had its margin removed, and so (as proved by hundreds of experiments) has been entirely deprived of its locomotor centres, nevertheless, in response to electrical stimulation, instead of giving a single contraction to make or break, it may begin a highly peculiar motion of a flurried, shivering character, which lasts without intermission for periods varying from a few seconds to half an hour. I never but once saw a similar motion in a perfect animal, and this was in the case of a specimen which was being poisoned with iron-rust. The motion may, I think, be explained by supposing that the various systems of muscles are contracting without coordination; but why they should sometimes do this in response to electrical stimulation, and why, when they do this, they should continue the action so long, these questions I cannot answer. In no other genus of the Medusæ have I ever seen a similar or corresponding action performed; and even in the genus *Sarsia* its occurrence is comparatively rare. It never begins spontaneously, and it appears to be most readily evoked by submitting the paralyzed nectocalyx to a number of shocks, either from the direct or the induced current, in somewhat rapid succession. When it does occur it is always continuous, *i. e.* it never spontaneously recommences after having once ceased. When its period of duration is prolonged, the shivering motions become feebler and feebler, until they eventually fade away into quiescence. The animal is then quite insensible to all further stimulation: the tissues appear to have died from exhaustion. These shivering motions may also be caused in *Sarsia* by slightly acidulating the water in which the mutilated nectocalyx is suspended.

§ 3. In their behaviour towards chemical stimuli, the excitable tissues of all the Medusæ conform in every respect to the rules which are followed by the nervo-muscular tissues of higher animals. Both the severed margins and the mutilated swimming-organs, as well, I may add, as severed polypites and tentacles, respond to applications of various acids, solutions of various metallic salts, alcohol, ether, glycerine, &c. Fresh water is quickly fatal to Medusæ.

§ 4. My observations upon thermal stimulation are, for the present, reserved.

IV. *Section.*

§ 1. The extent to which the swimming-organs of Medusæ may be mutilated without suffering destruction of their physiological continuity is in the highest degree astonishing.



(*a*) Suppose the annexed diagram to represent *Sarsia* in projection, the lines being cuts. It is evident that a stimulus originating at any point *a* in the margin cannot radiate its influence throughout the nectocalyx, except by traversing the course of the dotted line; yet in a specimen so cut the spontaneous contractions are as synchronous over the entire nectocalyx as they are in unmutilated specimens. Further, if the margin be now removed, the paralyzed bell will respond to stimuli applied at any part, just as readily and simultaneously over its whole extent as it would do were there no system of interdigitating cuts present.

(*b*) If the margin of *Sarsia* be removed in a continuous strip, with the exception of one end left attached *in situ*, and if the section be then continued in the form of a spiral having two or more turns from the base to the apex of the cone, the contractile waves originating in the free portions of the severed margin pass into the spiral upon reaching its point of origin, and then run round and round the spiral from the base to the apex of the cone. If the marginal strip be now removed altogether, the paralyzed bell will respond to stimuli applied to any part of the spiral.

(*c*) If seven lithocysts be removed from the gonocalyx of *Aurelia aurita*, and if the remaining one be made the point of origin of a spiral section, which is then carried round and round the disk-shaped gonocalyx, the result is a long strip of contractile tissue, the contractile waves always originating in the lithocyst at the end of the strip, and then running along the strip until they deliver themselves into the remainder of the gonocalyx, which thereupon contracts. The length and width of such contractile strips are very important factors in determining whether the waves pass all the way along the strip or become blocked at some point in its length. Nevertheless these are very far from being the only factors, there being immense individual differences in the endurance of the contractile tissue under this form of section. Sometimes the waves will become blocked when the strip is only an inch or less in length; while at other times the waves will pass freely from end to end of a contractile strip which is only an inch wide and a yard long.

§ 2. How are the impulses transmitted from the locomotor centres of Medusæ to the contractile tissues of their swimming-organs? Have we any evidence of more or less definite lines of discharge being present? or must we conclude that the contractile tissues are, throughout their extent, of a functionally homogeneous nature?

(*a*) The fact that the contractile tissues endure such severe section without losing their physiological continuity, appears to settle this question in favour of the last-mentioned alternative. Nevertheless there is a weighty body of evidence to be adduced on the other side. In the first place, the extreme variations in their tolerance of spiral section which are manifested by different individuals of the species *Aurelia aurita* appear to be irreconcilable with the hypothesis of the tissue concerned being functionally homogeneous. But the following invariable fact is still more difficult to reconcile with this hypothesis, viz. *at whatever point in a contractile strip that is being progressively elongated by section the contractile wave becomes blocked, the blocking is sure to take place completely and exclusively at that point.* In view of these facts, therefore, at the present stage of my inquiries, I provisionally accept the hypothesis of more or less definite lines of discharge being present in the swimming-organs of Medusæ. I have hitherto failed, however, to detect any such lines histologically.

(*b*) After the waves have become completely blocked in a contractile strip, it sometimes happens that the blocking is overcome, the waves again passing into the remainder of the gonocalyx as freely as they did before the section reached the point at which the blocking occurred. Sometimes, under these circumstances, the strip will admit of being further elongated for some distance before the waves are again blocked; and occasionally it happens that the second blockage is also thrown down. I have once seen four such successive blockages successively overcome.

It will be seen that these facts militate against the supposition of lines of discharge being present. I think, however, that there is a theory by which these facts admit of being satisfactorily reconciled with that supposition. But this whole subject awaits further and extensive investigation.

(*c*) Pressure exerted upon any transverse line in a contractile strip causes blocking of the waves at that line. If the pressure be slight, the blocking will be temporary; but if severe or long-continued, the blocking will probably be permanent. Even the slight strains caused by handling contractile strips in the air are often sufficient to show the rate of the waves, and sometimes to block them.

V. *Additional Facts tending to show the identity of the Locomotor Centres of Medusæ with Nervous Tissue in general.*

§ 1. Having placed several hundred *Sarsia* in a large bell-jar, I completely shut out the daylight from the room in which the jar was placed. By means of a dark-lantern and a concentrating-lens, I then cast a beam of light through the water in which the *Sarsia* were swimming. From all parts of the bell-jar the *Sarsia* crowded into the path of the beam. The presence of a visual sense in the case of this genus is therefore unquestionable.

Having removed twelve vigorous specimens from the large bell-jar and placed them in a smaller one, I excised the so-called eye-specks from nine of the number. The three unmutilated individuals sought the light as before; but the other nine swam hither and thither without paying it any regard. I conclude, therefore, that the visual faculty is lodged exclusively in the marginal bodies.

Lastly, I brought a heated iron, just ceasing to be red, close against the glass side of the large bell-jar; but no one of its numerous occupants approached the heated metal. Therefore the rays by which the *Sarsia* had been affected in the previous experiment were the properly luminous rays, and not the calorific ones.

§ 2. (*a*) The anæsthesiating influence of chloroform and ether is most decided, both in the case of the naked- and of the covered-eyed Medusæ. The first indications of approaching torpor are (*a*) decrease in the rate of the pulsations and (*b*) diminution of their vigour. These indications rapidly become more and more marked, so that shortly after they first set in the period of diastole is very much prolonged and the systoles, when they occur, are of the feeblest character. Eventually the pulsations altogether cease; and shortly after this stage of perfect quiescence has been reached, the Medusa is quite insensible to all stimulation. Recovery in normal sea-water is very rapid, occupying only a few seconds in the case of *Sarsia*; but, like the reverse process of anæsthesiation, it is clearly of a gradual nature.

(*b*) Morphia is as decided in its action upon Medusæ as is chloroform. The processes of anæsthesiation and of subsequent recovery are very similar to those just described, except that both processes occupy a somewhat longer time.

(*c*) Strychnia exerts a very marked influence upon Medusæ. Of the species I have met with *Cyanæa capillata* is the most suitable for showing the effects of this poison, from the fact that, in water kept at a constant temperature, the normal pulsations of this animal are as regular as are those of a heart. Shortly after a solution of strychnia has been added to the water in which a specimen of *C. capillata* is contained, unmistakable signs of irregularity in the pulsation of the animal supervene. This irregularity then increases more and more, until at last it grows into well-marked convulsions. The convulsions manifest themselves in the form of extreme deviations from the rhythmical character of the normal contractions, amounting, in fact, to nothing less than tonic spasms. It is further of importance to remark that the convulsions are very plainly of a paroxysmal nature—prolonged periods of uninterrupted convulsions being every now and then relieved by shorter periods of repose, during which the Medusa remains perfectly motionless in a fully expanded form. *C. capillata* will live for many hours when under the influence of strychnia, but eventually death supervenes. The animal dies in full diastole.

(*d*) Curare was administered by the following method. I placed the Medusa in a flat-shaped beaker filled to the brim with sea-water. This beaker I then placed in a large basin filled with sea-water up to the level of the water in the beaker. Having next divided the Medusa across its whole diameter, with the exception of a small piece of marginal tissue to act as a connecting-link between the two resulting halves, I transferred one of these halves to the water in the basin, leaving the other half still in the beaker. Lastly, I poisoned the water in the beaker with successive doses of urari solution. The species best suited for this experiment is *Staurophora laciniata*.

The effects of curare thus administered are most marked and beautiful. Previous to the administration of the poison both halves of the divided Medusa are, of course, contracting vigorously—the contractile waves now running from the half in the basin to the half in the beaker, and now *vice versâ*. But after the half in the beaker has been effectually poisoned all motion in it completely ceases, the unpoisoned half, however, continuing to contract independently. If the poisoned half be now irritated, by nipping with the forceps or otherwise, it does not itself move, but the other or unpoisoned half immediately responds to the stimulation. If *S. laciniata* be the species of Medusa employed, this result is particularly well marked, from the fact that the unpoisoned half responds to the stimulation by performing the highly distinctive spasmodic movements already described. I have also satisfied myself that curare asserts its peculiar influence upon individuals of the covered-eyed Medusæ. In all cases overpoisoning paralyzes the excitable as well as the motor system. The strength of the solution I used was 1 in 2500, and in this solution the poisoned half required to soak for half an hour.

(*e*) If any sized portion of a contractile strip cut from the gonocalyx of *A. aurita* be immersed in a sea-water solution of any of the above-mentioned anæsthesiating substances, the contractile waves in the poisoned portion of the strip are first progressively slowed and finally blocked. Upon now restoring the poisoned portion of the strip to normal sea-water, the contractile waves again begin to pass, and eventually do so as freely as before.

If any of the nutrient tubes which cross such a contractile strip transversely be injected with a solution of any of the narcotic poisons, the contractile waves become blocked at the line occupied by that tube. If a discharging lithocyst be similarly injected, it ceases its discharges. From the effects of chloroform and weak solution of morphia, however, it recovers in the course of a night. Alcohol so injected at first causes an increase in the frequency and potency of the discharges, and afterwards progressive torpor. In time, however, the torpidity wears away, and finally the Medusid returns to its normal state.

IV. "Note on the Placentation of *Hyrax*." By William Turner, M.B. (Lond.), Professor of Anatomy, University of Edinburgh. Communicated by Prof. Huxley, Sec. R.S. Received December 13, 1875.

In his 'Lectures on Comparative Anatomy,' vol. v. p. 326, Sir Everard Home stated that the placenta in *Hyrax capensis* is annular, like that in the cat; and in vol. vi. he gave two drawings of the placenta (pls. 61 & 62), in which he not only showed its zonary form, but figured, though he did not describe, the sac of the allantois as equalling in length the bag of the chorion. Prof. Owen, in his description of the placenta of the elephant (Phil. Trans. 1857), refers to the placenta of *Hyrax* as similar in spongy texture and vascularity to the annular placenta of the Carnivora, and ubsequently (Comp. Anat. Vertebrates, iii. p. 742) states that the villi are imbedded in a decidual substance, and the surface of attachment to the uterus is less limited than in the elephant. Prof. Huxley, in his Hunterian Lectures, 1863[*], described the placenta of *Hyrax* as having such an interblending of the fœtal and maternal portions that it is as truly deciduate as that of a rodent. In his 'Manual of the Anatomy of Vertebrated Animals,' 1871, he further points out that the maternal vessels pass straight through the thickness of the placenta towards its fœtal surface, that the allantois spreads over the interior of the chorion and gives rise to the broad zone-like placenta, and that the yelk-sac and vitello-intestinal duct early disappear.

In direct opposition to the views of these anatomists, M. H. Milne-Edwards has recently stated[†] that there is nothing in the placenta of *Hyrax* to indicate the presence of a caduca, and the allantois does not overstep the limits of the placental zone. The villi, he says, are mostly simple, very analogous to those of an ordinary pachyderm. In the midst of the zone vascular vegetations are engaged in corresponding uterine cavities, but they adhere no more than do the analogous prolongations in the ruminant to the crypts in which they are included; they can be detached with the same facility without tearing through any thing, and without carrying away any portion of uterine tissue. M. George, in an elaborate monograph on the genus *Hyrax*, published in June last[‡], figures not only the placenta, but the gravid uterus of this animal. He says nothing, however, of the structure, which he was apparently precluded from examining, but adopts the view of M. H. Milne-Edwards that it was non-deciduate.

The antagonism between the views of the English and French anatomists, not only as regards the structural details, but the conclusions as to the nature of the placentation, has rendered it advisable to have the placenta of *Hyrax* reexamined; and, with great liberality, Prof. Huxley has placed at my disposal his specimen, which had been preserved in spirit of wine. I shall now describe what I have seen.

The uterus was two-horned. Two well-developed ova, each about 3½ inches long, were in one cornu. One ovum had been opened, the membranes and placenta examined, and the fœtus removed; the other ovum was entire. The placenta was zonary, and varied in different parts of the zone from between ¼ to ½ inch in breadth, whilst the average thickness was $\frac{1}{10}$ inch. The non-placental areas of the chorion were smooth and translucent, and, as in the Carnivora, branches of the umbilical vessels ramified in them. The zone on the chorion was intimately blended with a corresponding zone in the uterine mucosa. When the placenta was stripped off the uterus, not only was the mucosa in the placental zone removed along with the chorion, but for some distance on each side of the zone the mucosa tore away from the muscular coat of the uterus.

---

[*] Elements of Comparative Anatomy, 1864, p. 111.

[†] Considérations sur la Classification des Mammifères, Paris, 1868.

[‡] Annales des Sciences Naturelles, 1875.

The fœtal surface of the placenta was smooth, and on it the umbilical vessels ramified before entering the villi of the chorion. Some injection was passed into them, but it did not flow into their intravillous branches. The uterine surface of the artificially separated placenta was flocculent; and the flocculi were seen, on microscopic examination, to consist of bundles of connective tissue intermingled with corpuscles, obviously the submucous connective tissue of the placental zone.

A toughish membrane, continuous on each side with the mucosa of the non-placental area of the uterus, could without difficulty be peeled off the uterine surface of the placenta as a well-defined layer. When examined microscopically, the surface of this membrane which lay next the uterus was seen to resemble in structure the flocculi projecting from it; whilst the part next the placenta was much more abundantly cellular, and stained readily with carmine. The surface which had been in apposition with the placenta was irregularly undulating, and divided into numerous shallow crypt-like recesses, separated from each other by raised folds of the membrane. These crypts were lined by a layer of cells, the nuclei of which were very distinct. I regard this membrane as the serotina, or modified uterine mucosa of the placental zone; whilst the crypts, with their epithelial lining, are the closed ends of the deep pits in which the villi of the chorion are lodged.

The substance of the placenta was then examined, with the object of determining not only the form of the fœtal villi, but if prolongations of the maternal mucosa passed into the placenta between the villi. In vertical sections the villi appeared as if simple filamentous structures, extending from the chorion to the crypt-like recesses in the serotina; but when portions of the placenta were teased out with needles, so that the villi were not injured, although an occasional simple villus was seen, the majority were broad, sinuous, leaf-like villi, with bud-like offshoots at the free border, such as I have described and figured in the domestic cat (Trans. Roy. Soc. Edinburgh, 1875). In horizontal sections through the placenta the sinuous outline of the villi presented so close a resemblance to the cat, that it was difficult in this particular to distinguish *Hyrax* from *Felis*. Under a magnifying-power of 320 diameters, a layer of flattened cells, the nuclei of which were almost circular and bright with transmitted light, was seen at the surface of the villus. Intermingled with the fœtal villi were laminar prolongations of the maternal mucosa, which invested and closely followed the sinuosities of the villi, similar to the arrangement I have described and figured in the domestic cat*. This intraplacental maternal tissue was present not only in those sections in which the serotina was *in situ*, but in others from which this membrane had been peeled off. The maternal laminæ were covered by a layer of cells, obviously continuous with the cellular lining of the crypt-like recesses on the free surface of the serotina, and the laminæ themselves were prolongations into the placenta of the folds of the mucosa which separated the crypts from each other.

---

* Memoir "On the Placentation of the Seals," already cited, 1875, p. 293, pl. xxi. fig. 14.

As the placenta of *Hyrax*, both in the form of its villi and in the mode in which they are interlocked between the intraplacental maternal laminæ, so closely resembles that of the domestic cat, and as these laminæ remain *in situ* after the membrane, which I have named the serotina, is peeled off the placenta, there can be no doubt that they are shed at the time of separation of the placenta. Hence *Hyrax*, in its placentation, is one of the Deciduata. Whether the membrane just referred to is also shed during parturition is more difficult to say. The fact that it peels off the uterus along with the placenta, when they are artificially separated, is not of itself sufficient evidence. In the cat the whole thickness of the mucosa in the placental zone peels off along with the placenta when that organ is artificially separated; whilst in normal parturition the deeper part of the connective tissue of the mucosa, with the remains of the blood-vessels and tubular glands, persists as a covering for the muscular coat, and forms a non-deciduous serotina. It may be that in *Hyrax*, as in the cat, only the superficial part of this membrane is shed with the placenta, whilst the rest remains on the zone of the uterus; but this can only be determined by the examination of a uterus immediately after parturition.

The non-placental area of the mucosa contained tubular glands, which, relatively to the extent of the membrane, were not nearly so numerous as in the gravid mucosa of animals having a diffused or polycotyledonary placenta. The glands were long, and the gland-stem was unbranched and almost straight; the closed end was dilated, bent on itself, and seemed to give off a short branch. The secreting epithelium did not fill up the tube, but left a central lumen.

When the chorion was cut through on either side of the placental zone, the sac of the allantois was opened into, and seen to extend up to the poles of the chorion. At and close to the margin of the placenta the allantois was reflected on to the outer surface of the amnion, to which it obviously gave a complete investment, so that the bag of the amnion was suspended in the sac of the allantois by the bands of the latter membrane reflected on to its outer surface. The amnion was large relatively to the sac of the allantois. The umbilical cord was short and somewhat flattened.

Numerous flattened plates, the largest of which were about $\frac{1}{10}$ inch in diameter, projected from the inner surface of the amnion. They were situated not only in the neighbourhood of the umbilical cord, but scattered as far as the poles. Some were sessile, others slightly pedunculated;

and as they were all covered by the epithelial lining of the amnion, they were apparently developed between it and the layer of allantois which covered its outer surface. The plates were obviously composed of cells the nuclei of which were distinct; but the toughness of the tissue, due probably to the prolonged action of the spirit in which the specimen had been preserved, rendered it difficult to isolate them. In position and structure these plates apparently corresponded to the amniotic corpuscles which I have described in *Orca gladiator* (Trans. Roy. Soc. Edinburgh, 1871).

The non-gravid uterine cornu was enlarged and contained two masses (one the size of a walnut, the other of a filbert) connected together by an intermediate neck. When examined microscopically they were seen to contain tubular glands and blood-vessels, lying in a richly corpusculated connective tissue. These masses were evidently the greatly hypertrophied mucosa, which had become thickened in sympathy with the changes in the gravid cornu. There was no extension of the fœtal membranes into this cornu, and its cavity seemed as if almost obliterated by the great hypertrophy of the mucous wall.

Hyrax agrees, therefore, with *Felis*, not only in the form and structure of the placenta, but in the presence of a large allantoic sac. It differs, however, in the condition of the umbilical vesicle, which in *Felis* persists during utero-gestation, but in *Hyrax* disappears apparently at an early period.

The Society then adjourned over the Christmas Recess, to Thursday, January 6, 1876.

Presents received, December 9, 1875.

Transactions.

Calcutta:—Asiatic Society of Bengal. Journal, 1874. Part 1. No. 4, Part 2. No. 4; 1875. Part 1. No. 1. Part 2. No. 1. 8vo. *Calcutta.* Extra Number. 8vo. *Hertford* 1875. Proceedings, 1874. No. 10; 1875. No. 1–6. 8vo. The Society.

Newcastle-upon-Tyne:—North of England Institute of Mining and Mechanical Engineers. Transactions. Vol. XXIV. 8vo. 1875. The Institute.

Rome:—Accademia Pontificia de' Nuovi Lincei. Atti. Anno 28. Sess. 4–6. 4to. *Roma* 1875. The Academy.

Turin:—R. Accademia delle Scienze. Atti. Vol. X. Disp. 1–8. 8vo. *Torino* 1874–75. The Academy.

Yokohama:—Asiatic Society of Japan. Transactions. Vol. III. Part 1. 8vo. 1875. The Society.

Reports, Observations, &c.

Bombay:—Detailed Census Returns of the Bombay Presidency. Part 3. folio. 1875. The India Office.

Calcutta:—Report of the Commissioners appointed to inquire into the Origin, Nature, &c. of Indian Cattle Plagues, with Appendices. folio. 1871. The India Office.

Dehra Dun:—Great Trigonometrical Survey of India. Synopsis of the Results of the Operations. Vol. IV. The Gurhagarh Meridional Series, by Colonel J. T. Walker, F.R.S. 4to. 1875. The India Office.

Another Copy. The Indian Government.

London:—Admiralty. Catalogue of the Books in the Library, by Richard Thorburn. 4to. 1875. Nautical Almanac for 1879. 8vo. 1875. The Admiralty.

Meteorological Office. Weather Reports. Jan. 1 to June 30, 1875. folio. Hourly Readings from Self-recording Instruments. June 1875. folio. The Office.

Milan:—Reale Osservatorio di Brera. Pubblicazioni. No. 4, 5, 8, 9, 10. 4to. 1874–75. The Observatory.

Turin:—Osservatorio della Regia Università. Bollettino Meteorologico ed Astronomico. Anno 8, 1873. 4to. *Torino* 1875. The Observatory.

Duncan (P. M.), F.R.S. On the Fossil Corals of the West-Indian Islands. 4 Parts. 8vo. *London* 1863–68. On the older Tertiary Formations of the West-Indian Islands. 8vo. 1873. Geology of Jamaica. 8vo. 1865. Fossil Corals from Sinde. 8vo. 1864. Corals of the Maltese Miocene. 8vo. 1865. Coral Faunas of Western Europe. 8vo. 1870. Second and Third Reports on the British Fossil Corals. 8vo. 1869–71. On the Madreporaria of the Infra-Lias of South Wales. 8vo. 1867. On the Madreporaria from the "Sutton Stone." 8vo. 1866. On the 'Porcupine'-Expedition Madreporaria. 8vo. 1870. Impressions of Selenite. 8vo. 1865. The Author.

Everett (J. D.) Illustrations of the Centimetre-Gramme-Second (C.G.S) System of Units. 8vo. *London* 1875. The Author.

Hæckel (Ernst) The History of Creation: or the Development of the Earth and its Inhabitants by the action of Natural Causes; the translation revised by E. Ray Lankester, F.R.S. 2 vols. 8vo. *London* 1876. C. Darwin, F.R.S.

Kronecker (L.) Über die congruenten Transformationen der bilinearen Formen. 8vo. *Berlin* 1874. Über Schaaren von quadratischen und bilinearen Formen. 8vo. 1874. Über quadratische Formen von negativer Determinante. 8vo. 1875. Über die algebraischen Gleichungen, von denen die Theilung der elliptischen Functionen abhängt. 8vo. 1875. The Author.

Pengelly (W.), F.R.S. The Flint and Chert Implements found in Kent's Cavern, Torquay. 8vo. *Plymouth* 1875. The Author.

Scott (Michael) Occasional Papers. Vol. I. Civil Engineering. Vol. II. Gunnery and Naval Architecture. 2 vols. 8vo. *London* 1874. The Author.

December 16, 1875.

Transactions.

Bologna:—Accademia delle Scienze dell' Istituto. Memorie. Serie 3. Tomo III. fasc. 2–4; Tomo IV. 4to. 1873–74. Rendiconto delle Sessioni. 1873–74. 8vo. The Academy.

Bordeaux:—Société de Médecine et de Chirurgie. Mémoires et Bulletins. 1874, fasc. 3, 4; 1875, fasc. 1, 2. 8vo. The Society.

Dresden:—Verein für Erdkunde. XI. und XII. Jahresbericht. 8vo. 1875. The Institution.

Heidelberg:—Naturhistorisch-medicinischer Verein. Verhandlungen. Neue Folge. Band I. Heft 2. 8vo. 1875. The Institution.

Hermannstadt:—Siebenbürgischer Verein für Naturwissenschaften. Jahrgang XXV. 8vo. 1875. The Institution.

Jena:—Medicinisch-naturwissenschaftliche Gesellschaft. Band IX. Heft 3, 4. 8vo. 1875. The Society.

London:—British Pharmaceutical Conference. Transactions at the Twelfth Annual Meeting, held in Bristol, August 1875. Year-Book of Pharmacy. 8vo. 1875. The Conference.

Institution of Civil Engineers. Minutes of Proceedings. Vol. XLII. Session 1874–75. Part 4. 8vo. 1875. The Institution.

Royal Society of Literature. Transactions. Second Series. Vol. XI. Part 1. 8vo. 1875. The Society.

Milan:—Fondazione Scientifica Cagnola. Atti. Vol. VI. Parte 1. 8vo. 1872. The Institution.

Montpellier:—Académie des Sciences et Lettres. Mémoires. Section des Sciences. Tome VI. fasc. 2, 3; Tome VII.; Tome VIII. fasc. 1, 2. 4to. 1865–73. Section de Médecine. Tome IV. fasc. 3–6. 4to. 1865–72. Section des Lettres. Tome IV. fasc. 2–4; Tome V. fasc. 1–4. 4to. 1866–73. The Academy.

Paris:—Société de Géographie. Bulletin. Mai–Sept. 1875. 8vo. The Society.

Société Géologique de France. Bulletin. 3^e Série. Tome II. No. 7, 8; Tome III. No. 5–7. 8vo. 1874–75. The Society.

St. Petersburg:—Académie Impériale des Sciences. Mémoires. Tome

Transactions (*continued*).

XXI. No. 6–12; Tome XXII. No. 1–3. 4to. 1874–75. Bulletin. Tome XIX. No. 4, 5; Tome XX. No. 1, 2. 4to. 1874–75. The Academy.

Würzburg:—Physikalisch-medicinische Gesellschaft. Verhandlungen. Neue Folge. Band VIII. Heft 3, 4. 8vo. 1875. The Society.

Reports &c.

Barbadoes:—Report upon the Rainfall of Barbadoes, and upon its influence on the Sugar Crops, 1847–71, by Governor Rawson. folio. 1874. The Author.

Brisbane:—Statistics of the Colony of Queensland for the year 1873. folio. 1875. The Government of the Colony.

Calcutta:—Report of the Meteorological Reporter to the Government of Bengal for 1874, by W. G. Willson. folio. 1875. Report of the Midnapore and Burdwan Cyclone of the 15th and 16th of October, 1874, by W. G. Willson. folio. 1875. The Government of Bengal.

Report on the Operations connected with the Observation of the Total Solar Eclipse of April 6, 1875, at Camorta, in the Nicobar Islands, by Captain J. Waterhouse. folio. *Calcutta* 1875. The Indian Government.

Liverpool:—Report of the Astronomer to the Marine Committee, Mersey Docks and Harbour Board, for the years 1873–74. 8vo. 1875. The Board.

Ottawa:—Reports of the Meteorological, Magnetic, and other Observatories of the Dominion of Canada for the year ending Dec. 31, 1874. 8vo. 1875. Meteorological Office, Toronto.

Pulkova:—Observatory. Observations de Poulkova publiées par Otto Struve. Vol. VI. 4to. *St. Pétersbourg* 1873. Jahresbericht am 27. Mai 1874, dem Comité der Nicolai-Hauptsternwarte. 8vo. 1874. Observations des Satellites de Jupiter. 8vo. 1872. Die Polhöhe von Pulkowa, von M. Nyrén. 4to. 1873.

Andrews (Dr. T.), F.R.S. Address on Ozone. roy. 8vo. *Edinburgh* 1874 (2 copies). The Author.

Blacker (Rev. B. H.) Brief Sketches of the Parishes of Booterstown and Donnybrook, in the County of Dublin. Part 4. 12mo. *Dublin* 1874. The Author.

Cremona (L.) Éléments de Géometrie Projective, traduits par Ed. Dewulf. Partie 1. 8vo. *Paris* 1875. The Author.

De La Rue (Warren), F.R.S. Auxiliary Tables for determining the Angle of Position of the Sun's Axis, and the Latitude and Longitude of the Earth referred to the Sun's Equator. 4to. *London* 1875 (3 copies). The Author.

Kerz (Ferdinand) Die Entstehung des Sonnensystems nach der Laplace'schen Hypothese in verschiedenen neuen Richtungen ausgeführt. 8vo. *Darmstadt* 1875. The Author.

M'Lachlan (R.) A Monographic Revision and Synopsis of the Trichoptera of the European Fauna. Part 3. 8vo. 1875. The Author.

Ross (Dr. A. M.) The Birds of Canada. Second Edition. 12mo. *Toronto* 1872. The Butterflies and Moths of Canada. 12mo. 1873. A Classified Catalogue of the Birds of Canada. 12mo. 1872. The Forest Trees of Canada. 12mo. 1875. The Flora of Canada. 12mo. 1875. Canadian Illustrated News, Oct. 3, 1874. The Author.

Suess (Eduard) Die Entstehung der Alpen. 8vo. *Wien* 1875. The Author.

Vinchon-Thiesset (A.) La Cause des Effets. 8vo. *Saint Quentin* 1875. The Author.

Bronze Medals of Joseph Black, M.D., and William Hunter, M.D., by Macphail of Glasgow. Dr. Sharpey, F.R.S.

January 6, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Expansion of Sea-water by Heat." By T. E. Thorpe, Ph.D., and A. W. Rücker, M.A. (Fellow of Brasenose College, Oxford), Professors of Chemistry and Physics in the Yorkshire College of Science. Communicated by W. B. Carpenter, M.D., LL.D., F.R.S. Received November 12, 1875.

(Abstract.)

The extensive contributions which have recently been made to the physical history of the ocean have shown the desirability of exact knowledge of the relations of sea-water to heat. We have accordingly thought it worth while to make observations in order to determine the law of the thermal expansion of sea-water.

The only attempt hitherto made to solve this problem which can lay any real claim to consideration is due to the late Professor Hubbard, of the United States National Observatory. The results of his investigation are contained in Maury's 'Sailing Directions,' 1858, vol. i. p. 237.

Muncke, nearly fifty years ago, determined the expansion of an artificial sea-water at various temperatures between 0° and 100° C.; but our confidence in the results as applicable to natural sea-water is affected by the circumstance that the solution was prepared from data furnished by the imperfect analyses of Vogel and Bouillon La Grange.

The observations of Despretz were confined to temperatures below 13°·27, as the main object of his inquiry was the determination of the point of maximum density of sea-water. The subsequent investigations of Neumann and Rossetti were equally limited, as they were undertaken with the same view.

The water used in our observations was collected from the Atlantic, in lat. 50° 48′ N. and long. 31° 14′ W.; and its specific gravity at 0° C., compared with distilled water at the same temperature, was found by the bottle to be 1·02867.

The method of experiment was precisely the same as that already employed by one of us in determining the expansion of the liquid chlorides of phosphorus. It was essentially that already used by Kopp and Pierre; *i. e.* the expansion was observed in thermometer-shaped vessels (so-called dilatometers), graduated and accurately calibrated.

Three of these instruments and two sets of thermometers were employed. The latter were made by Casella; the length of a degree in different instruments varied between 9 and 13 millims.; they had been compared (the one set directly, the other indirectly) with Kew Standards.

Three perfectly independent sets of observations were made with the water in the state in which it was collected; and as Mr. Buchanan, of H.M.S. 'Challenger,' has found that the specific gravities of different sea-waters lie between the extreme values 1·0278 and 1·0240, and since, in order to be of value in the investigation of the physical condition of the ocean, the observations on their values and the formulæ of reduction ought to be correct to the fourth decimal place, we diluted quantities of our sea-water with distilled water, so as to have specimens of approximately the specific gravities of 1·020 and 1·025; and we concentrated a third quantity by evaporation until its specific gravity was increased to 1·033, and made two series of independent observations on the expansion of each solution.

As we wished to confine ourselves to circumstances to which sea-water s naturally exposed, we did not carry on our experiments at temperatures higher than 40° C.

Empirical formulæ were calculated to express the results of each series of observations; and in the original paper full details of the observations are given, together with Tables showing the agreement between the calculated and observed results, and also (after the necessary corrections and reductions have been made) between the volumes calculated from the formulæ from different series of observations on the same solutions.

Finally, a general formula of the form

$$v=\phi(t)+\psi(t)f(s)$$

was found, giving the relation between the volume (v), temperature (t), and specific gravity at 0° C. (s) of any solution of the same composition of sea-water the specific gravity of which at 0° C. lies between 1·020 and 1·033, the volume at the same temperature being taken as unity; in which expression

$$\phi(t)=1+{\cdot}00008097t+{\cdot}0000049036t^2-{\cdot}000000012289t^3,$$
$$\psi(t)=-10^{-5}({\cdot}5509t-{\cdot}020198t^2-{\cdot}00033276t^3),$$
and $$f(s)=11{\cdot}95-940(s-1{\cdot}02)$$[*].

In the original paper we show that if σ be the specific gravity at any temperature t of a solution the specific gravity of which at 0° C. is s, we may without sensible error assume $\frac{d\sigma}{ds}$ to be constant; whence, by means of the above formula, we are able to give in the following Table all the data necessary for calculating the specific gravity of sea-water of any degree of salinity at any temperature between 0° and 36°. Column II. contains the specific gravities at the temperatures given in Column I. of a solution the specific gravity of which at 0° C. is 1·02000; Column III. contains the numbers which must be subtracted from those in Column I. for each increase of 0°·1 over the temperatures opposite to which they are placed; and Column IV. the numbers which must be added for each increase of ·00001 of the specific gravity of the solutions at zero. At the heads of Columns III. and IV. are the numbers of ciphers which must be prefixed to the figures written in them in the unit place.

In order to facilitate the use of the Table, we subjoin directions for its application in the form of rules, and give a couple of examples.

I. Given the specific gravity of a sample of sea-water at any temperature t, to find it at 0° C.:—Look out in Column I. the figure giving the number of entire degrees of the temperature; multiply the corresponding number in III. by the fraction by which the observed temperature exceeds that number, and subtract the result from the corresponding number in Column II. Subtract the difference from the observed specific gravity, and divide the number so obtained by that corresponding to the observed temperature in Column IV. (without prefixing the ciphers at the top of the column); add the quotient to 1·02000, and the sum will be the specific gravity required.

Example I. Specific gravity observed at 18°·5 C.=1·02475. Number

---

[*] The numerical constants involved in the above formula are given in the forms in which they were, for facility of calculation, determined. The expression can of course be easily transformed to the simpler form, $v=F_1(t)+sF_2(t)$.

Temperature.	Specific gravity.	Proportional parts for 1° C.	Proportional parts for ·00001 increase in spec. grav.	Temperature.	Specific gravity.	Proportional parts for 1° C.	Proportional parts for ·00001 increase in spec. grav.
°		·0000	·0000	°		·0000	·0000
0	1·02000	3	1	19	1·01740	25	0·944
1	1·01997	4	0·995	20	1·01715	25	0·943
2	1·01993	5	0·990	21	1·01690	26	0·941
3	1·01988	6	0·986	22	1·01664	27	0·940
4	1·01982	8	0·932	23	1·01637	28	0·938
5	1·01974	9	0·879	24	1·01609	29	0·937
6	1·01965	11	0·975	25	1·01580	29	0·935
7	1·01954	12	0·972	26	1·01551	30	0·934
8	1·01942	13	0·969	27	1·01521	30	0·932
9	1·01929	14	0·966	28	1·01491	31	0·930
10	1·01915	15	0·963	29	1·01460	32	0·928
11	1·01900	17	0·961	30	1·01428	32	0·925
12	1·01883	17	0·958	31	1·01396	32	0·922
13	1·01866	19	0·956	32	1·01364	33	0·919
14	1·01847	20	0·954	33	1·01331	33	0·915
15	1·01827	21	0·952	34	1·01298	33	0·912
16	1·01806	21	0·950	35	1·01265	34	0·908
17	1·01785	22	0·948	36	1·01231	34	0·903
18	1·01763	23	0·946				

opposite 18 in Column III. is ·00023, which multiplied by ·5 equals ·00011; and

$$1{\cdot}01763-{\cdot}00011=1{\cdot}01752.$$

Subtract this from the observed specific gravity,

$$1{\cdot}02475-1{\cdot}01752={\cdot}00723.$$

Divide by ·945 (the number corresponding to 18·5), and the quotient is ·00765, which added to 1·02000 gives 1·02765 as the specific gravity at 0° C.

Example II. Specific gravity observed at 15° C. =1·02570.

$$1{\cdot}02570-1{\cdot}01827={\cdot}00743,$$

and

$$\frac{{\cdot}00743}{{\cdot}952}={\cdot}00780.$$

Therefore specific gravity at 0° C. =1·02780.

We next discuss the discrepancies which occur between our own results and those of Professor Hubbard; and we point out various circumstances in the methods employed in making and reducing the latter observations which appear to us to explain in a great measure the divergences which exist.

II. "On the Action of Light on Tellurium and Selenium." By Prof. W. G. Adams, F.R.S. Received November 10, 1875.

Two platinum wires were attached to the ends of a small bar of tellurium, about 1 inch in length, by heating the wires to a bright red heat and bringing them suddenly in contact, one with each end of the bar. The platinum wires melted a small portion of the tellurium, and became imbedded in it. The resistance of the bar and wires was about half an ohm. The tellurium was placed in a box, and its resistance balanced; then it was exposed to the light of a paraffin-lamp, just as in the experiments with selenium. At first the light seemed to have no effect; but in consequence of the heat from the lamp, the resistance of the tellurium was increased.

On placing a rectangular vessel of water between the lamp and the tellurium and then exposing as before, there was no change of resistance in the tellurium, showing that if there was any diminution in the resistance due to the action of light it was entirely balanced by the increase in the resistance due to heating by the current and by the residual portion of the radiant heat.

On replacing the rectangular vessel of water by a beaker of water, so as to focus the light of the lamp on the tellurium, there was found on exposure to be a *diminution in the resistance of the tellurium*, which gradually increased until the galvanometer-needle was deflected through 30 divisions of the scale. The needle was then brought back to zero by altering one of the slide-resistances in the circuit. The agreement between the amounts of the change of resistance in several successive experiments, with intervals between them, was very close. Thus, in three experiments on October 8th,

The change in the first experiment was 124 millims. of wire,
" " second " " 120 " "
" " third " " 122 " "

showing a diminution in the resistance of the tellurium amounting to about one thousandth part of its whole resistance on exposure to the light of the paraffin-lamp.

On repeating the experiments with the tellurium which had not been exposed to light for seven days, the tellurium was found to be much more sensitive. When exposed at a distance of about half a metre, as before, to the paraffin-lamp the needle was gradually deflected through 30 divisions of the scale, showing that the resistance of the tellurium was now *diminished* as much without interposing the beaker of water as it had previously been when the beaker was interposed. On making no change whatever, except placing the beaker of water between the lamp and the tellurium, so as to focus the light on the tellurium, the deflection of the needle gradually increased to 80 and then more slowly to 100 divisions. On balancing this deflection, it was found that, to bring the needle to zero, it was necessary to diminish the slide-resistance by 400 millims. Thus the diminution produced in the resistance by exposure to the light of the paraffin-lamp was $\frac{1}{800}$ part of the whole resistance of the tellurium.

On exposing the selenium bar used in my experiments to the direct rays of the same paraffin-lamp at the distance of 1 metre, the resistance of the selenium was diminished by one fifth of its whole resistance.

From the above experiment we see that at the distance of half a metre (that is, with light of four times the intensity) the change of resistance in the tellurium under the same conditions is only $\frac{1}{1000}$ part of its whole resistance.

On exposing the selenium to a constant source of light at different distances, the change in the resistance of the selenium on exposure for 10 seconds (as measured by the swing of the galvanometer-needle) is almost exactly inversely as the distance, *i. e.* directly as the square root of the illuminating power. This law is true whether the source of light be 1 candle or an Argand lamp whose illuminating power is equal to 16 candles.

Taking the mean of a number of experiments, all of which agreed pretty well together, the deflections at the several distances were :—

	At ¼ metre.	At ½ metre.	At 1 metre.	At 2 metres.
With Argand lamp	..	170	83	39
„ candle..........	..	41	18	8
„ candle..........	82	39	18	8

Another series of experiments with a candle and Argand lamp (when the illuminating power of the lamp was equal to 12 candles), both at the distance of 1 metre, gave the following results :—

With the candle the deflection was 19 in 10 seconds.
„ Argand lamp „ 66 „

The ratio of the deflections is very nearly 1 to 3½.

These experiments clearly show that the change in the resistance of the selenium is *directly as the square root of the illuminating power.*

[*Correction.*—In my former paper on this subject (Proc. Roy. Soc. vol. xxiii. no. 163), on page 536, line 15, omit the word "opposing," and line 21, for "which opposes" read "in the same direction as;" also on page 539, line 25, for "which opposes a" read "in the same direction as the"; to the end of line 26 add "but in the opposite direction."]

III. "On the Refraction of Sound by the Atmosphere." By Prof. OSBORNE REYNOLDS, Owens College, Manchester. Communicated by Prof. STOKES, Sec. R.S. Received November 22, 1875.

(Abstract.)

This paper may be said to consist of two divisions. The first contains an account of some experiments an[illegible]servations undertaken with a view to ascertain how far the refraction of sound caused by the upward variation of temperature may be the cause of the difference in the distances to which sounds of the same intensity may be heard at different times.

Some rockets, capable of rising 1000 feet and then exploding a cartridge containing 12 oz. of powder, having been procured, an effort was made to compare the distance at which the rockets could be heard with that at which a gun, firing ¼ lb. of powder and making a louder report than the rockets, could be heard under the same conditions of the atmosphere. In the first instance the rockets and the gun were fired from a spot in Suffolk around which the country is tolerably flat, observers being stationed at different distances. Owing, however, to the effect of the wind and the time required for the observers to proceed to the distant stations, these experiments were not successful in establishing the comparative merits of the gun and the rockets. They were, however, important as showing that on hot calm days in July the reports of the rockets never failed to be distinctly audible at distances of 4 and 5 miles, although the sun at the time was shining with full force on the ground and rendering the air near the surface so heterogeneous that distant objects seen through it appeared to wave about and twinkle.

The next attempt was made during a cruise on the east coast. After three weeks cold and windy weather, the 19th of August was a fine day; and some experiments were made in Lynn Deeps, which revealed a very extraordinary state of the atmosphere as regards the transmission of sound. A party rowed away from the yacht in one of her boats, it having been arranged beforehand that either a rocket or a large pistol was to be fired from the yacht when signalled for; also that when those on the yacht heard those in the boat call they should answer. The boat proceeded to a distance of 5 miles, until those on the yacht had completely lost sight of it; but all the time the calls from the boat were distinctly heard by those on the yacht, although after they had lost sight of the boat they ceased to answer the calls. On the boat also not only were the reports of the pistol and rockets distinctly heard, but every answer from the yacht was heard plainly. The last came after an interval of 35 seconds, which gave the distance 3½ miles. Nor was this all; but guns, and on one occasion the barking of a dog, on the shore 8 miles distant were distinctly heard, as were also the paddles of a steamer 15 miles distant.

The day was perfectly calm, there was no wind, the sky was quite clear, and the sun was shining with great power—conditions which have been described as most favourable to the stoppage of the sound by the heterogeneity of the atmosphere, and which may also be described as most favourable for great upward refraction. On this day, however, it was observed that all the time distant objects *loomed* considerably, *i.e.* appeared lifted. This showed that the air was colder near the surface of the sea than it was above. It is to this circumstance that the extraordinary distances to which sounds were heard on this day is supposed to be due. The diminution in the temperature of the air being downwards, the sound, instead of being lifted as it usually is, was brought down, and thus intensified at the surface of the water, which, being perfectly smooth, was thus converted into a sort of whispering-gallery.

The report of the pistol and the sounds of the voice were attended with echoes, but not so the reports of the rockets; and it is suggested that these so-called echoes may be found only to attend sounds having a greater intensity in one direction than in another.

The second part of the paper refers to a phenomenon noticed by Arago in his report of the celebrated experiments on the velocity of sound made on the nights of the 21st and 22nd of June, 1822.

It was then found that, although the guns fired at Montlhéry could be distinctly heard at Villejuif (11 miles distant), those fired at Villejuif could not be heard at Montlhéry without great attention, and at times (particularly on the second night) they were not heard at all—although on both nights the wind was blowing from Villejuif to Montlhéry, the speed of the wind, which was very light, being about 1 foot per second. No explanation of this phenomenon was offered by the observers, although it was much commented on. And on the second night the gun at Villejuif, which on the previous night had been pointed upward, was brought down in the hope that this might improve its audibility (this step, however, was found to render matters worse than before).

From this lowering of the gun at Villejuif it seemed as though there was probably some difference in the conditions under which the guns at the two stations were placed, as if that at Villejuif was fired from a level, while that at Montlhéry might be fired over a parapet. An inspection of the district confirmed this view; for Villejuif is on a low flat hill, while Montlhéry is on the top of a steep cone; and not only is it 80 feet above Villejuif, but it is surmounted by the mound of an old castle, which is supported by a vertical wall towards Villejuif and surrounded by a low rampart. Hence it is suggested that in all probability the advantage of the gun at Montlhéry was due to its being fired over this parapet, while that at Villejuif was fired from the level ground.

The fact that the wind blowing from Villejuif did not reverse this advantage, suggested the possibility that at night, when the diminution of temperature is downward, a light wind may not produce the same effect upon sound as when the diminution of temperature is upward, as it generally is during the day.

To ascertain if this is the case, some observations were made on some calm nights in May and June of the present year, from which it was found:—

(1) That when the sky was cloudy and there was no dew, the sound of an electric bell 1 foot above the grass could always be heard further with the wind than against it; but

(2) that when the sky was clear and there was a heavy dew, the sound could invariably be heard as far against a light wind as with it, and in some cases much further. On one occasion, when the temperature at 1 foot above the grass was 38° and at 8 feet 47°, and the speed of the wind was 1 foot per second at 5 feet above the grass, the bell was heard 440 yards against the wind and only 270 with it.

Since, therefore, on the nights of the experiments at Villejuif and Montlhéry it is stated that the sky was clear, that there was dew, and the temperature recorded at the two stations shows the diminution to have been downwards, it is argued that the effect of the wind to render the sound less audible at Villejuif was completely balanced by the downward refraction of temperature.

Another phenomenon recorded by Arago is, that while the reports of the guns at Montlhéry as heard at that station were attended with prolonged echoes, this was not the case with those at Villejuif. It is thought that this difference is sufficiently accounted for by the fact that while Montlhéry is surrounded by high hills with precipitous or wooded sides, which must produce echoes, the country in front of Villejuif is very flat and has not a tree upon it for miles.

In concluding the paper reference is made to the Appendix to the last Report of the American Lighthouse Board, in which Dr. Henry, the Chairman, gives an account of his experiments, extending over thirty years, and the conclusions to which they have led him, both of which are in favour of the apparent stoppage of the sound being due to refraction.

IV. "On the Length of the Spark from a Battery of 600, 1200, 1800, and 2400 rod-Chloride-of-Silver Cells, and some Phenomena attending the Discharge of 5640 Cells." By WARREN DE LA RUE, D.C.L., F.R.S., and HUGO W. MÜLLER, Ph.D., F.R.S. Received January 6, 1876.

On the 24th February, 1875 *, we had the honour of communicating to the Society, in conjunction with our friend Mr. Spottiswoode, an account of some experiments to ascertain the cause of stratification in electrical discharges *in vacuo*. These experiments were made with a battery of 1080 cells of powder chloride of silver, which was described; we have now in action 3240 such cells, and have recently completed 2400 rod-chloride-of-silver cells †, making our total force 5640 cells in action. To these will be shortly added another unit of 1080 cells powder chloride, and two other units of 1200 rod chloride, making a total of 9120 cells.

We have more recently made a verbal communication to the Society of

---

* Proc. Roy. Soc. no. 160, 1875.

† *Ibid.* p. 357.

Telegraph Engineers, and also in October last a written one to the Académie des Sciences of Paris *, wherein we have stated that the length of the spark in air appears to be in the direct ratio of the square of the number of cells.

Having completed the 2400 cells, and charged them up in a single day, they were exactly in the same condition as to electromotive force and internal resistance; consequently they afforded the means of testing the truth of the law of the length of spark in a manner more efficacious than had hitherto obtained, the more especially as by the use of paraffin corks and other precautions we had obtained an excellent insulation.

Our assistant, Mr. Fram, has constructed a discharger which permits of the accurate measurement of the distance of the terminals to read to $\frac{1}{1000}$ of an inch, and by estimation to the tenth of that quantity. The nut through which the screw ($\frac{1}{50}$-of-an-inch thread) carrying one of the terminals works is divided into two parts, which are separated by a spiral pressure-spring so as to prevent shake. In making measurements the terminals are separated to a greater quantity than the anticipated striking-distance, and gradually approached until the spark passes; the discharger is then detached from the battery, and, after reading the scale, connected up with a separate battery of 10 cells, with a detector-galvanometer in circuit. The terminals are again approached until the motion of the galvanometer indicates contact between them; the scale is again read, and the length of spark obtained by the difference between the first and second reading.

Rod chloride,	600 cells had a striking-distance of			0·0033 in.
„	1200	„	„	0·0130 „
„	1800	„	„	0·0345 „
„	2400	„	„	0·0535 „

Taking as the unit 600 cells, the spark of which was 0·0033, the length of spark of 1200, 1800, 2400 would, according to theory, be that number multiplied by the square of 2, 3, 4 respectively.

600 cells, striking-distance		....	0·0033 in.
1200	„	0·0033 × 4	0·0132 „
1800	„	0·0033 × 9	0·0297 „
2400	„	0·0033 ×16	0·0528 „

which numbers agree nearly with those obtained by experiment.

The length of the spark is much influenced by the shape of the terminals; those which we frequently employ consist of a point as one terminal and a plane for the other. Hitherto we have used copper terminals, making the point and the plane alternately positive and negative by

---

* Comptes Rendus, no. 16, p. 686, & no. 17, p. 746 (1875).

means of a double key discharger, or by a rapidly revolving commutator reversing up to 352 times in a second. One terminal in the above determinations consisted of a point of 30°, and the other of a slightly convex surface 0·46 inch in diameter.

While making these measurements, we noticed in a nearly dark room that when the point was negative a glow, in form like a paraboloid, was seen surrounding it long before the spark passed, and its appearance afforded, by its increasing brilliancy, useful information to guide us as to the more cautious approach of the terminals; gradually the sugar-loaf-like glow extended to the positive terminal. With 1800 cells the glow was seen when the terminals were 0·0545 inch apart, the spark passing at 0·0345 inch; with 2400 cells the glow began at a distance of 0·0865 inch, the spark passing at 0·0535 inch. Moreover it was noticed that the disk (positive) became covered all over with a peach-like bloom, which became stronger in the centre as the terminals were made to approach each other, giving rise to Newton's iridescent rings.

In order to study more readily the phenomena accompanying the glow preceding the spark, the whole series of 5640 cells was used, the terminals being a point as before of 30° for one, and sometimes a flat disk 1·1 inch in diameter or a slightly convex one of 0·8 inch in diameter for the other. In all cases a peach-like bloom deposited on the disk, which was connected with the silver (positive) terminal; and when the flat disk was used the deposit was notably greater at the periphery and the centre than in other portions of it. With this number of cells,

With the flat disk the glow occurred at 1·073 in., the spark at 0·139 in.
With the slightly convex disk „ 1·124 in. „ 0·140 in.*

To ascertain whether a current really passed when the glow appeared, various vacuum-tubes were interposed in circuit between the battery and one of the terminals; in all cases they were illuminated even before a glow was perceptible on the negative pole; their interposition, as was to be expected, shortened the spark and diminished the distance at which the glow was perceptible. For example, with a hydrogen tube, having a capillary portion between two larger tubes, such as is used for spectrum experiments, and offering a resistance of 190,000 ohms, the glow occurred at 0·939 inch, the spark at 0·092 inch.

A tube of 31 inches between the terminals, and offering a resistance of 350,000 ohms, was brilliantly illuminated when interposed between one terminal and the battery; when the terminals were separated the extreme range of the discharge was 1·2 inch, and before any glow was visible at the negative electrode. How much further between the electrodes it will be possible to obtain a current has yet to be determined with a larger discharger now in course of construction*.

---

* *Postscript*, Jan. 7th.—At the suggestion of Professor Stokes, who saw the experiment repeated, the point was made positive, when a longer spark was obtained, namely 0·154 inch and 0·164 inch.

We have alluded to the resistance offered by vacuum-tubes. At first we experienced considerable difficulty in measuring it. For example, when in a Wheatstone's bridge the resistance of the tube was balanced by inserted resistances, the galvanometer could only for a short time be brought to rest, and it was then found that the cause of this was that the tubes rapidly increased in resistance as the current passed. After a time, however, they recovered their original resistance, sometimes rapidly, sometimes only after the lapse of days. The resistances were found not to be dependent on the length of tube, but to a great extent on their bore, capillary tubes offering a considerable resistance. Ultimately it was found that it was better to discard the indications of the galvanometer, and to rely solely on the appearance of a luminosity in the tubes placed on one side of Wheatstone's bridge as soon as the insertion of a balancing resistance was made in the other.

Later on we hope to have the honour of sending to the Society a more detailed statement of our experiments in support of those now quoted, and in confirmation of our former paper on the cause of stratification in electric discharges *in vacuo*.

In conclusion we venture to draw attention to the following consequences of the law of the length of spark being dependent on the ratio of the square of the number of cells of a voltaic battery, in the event of its being confirmed by experiment. Taking as a basis the spark with 600 cells of the rod-chloride-of-silver battery = 0·0033 inch, a unit of 1000 such cells would give a spark of $\frac{\cdot 0033 \times 1000^2}{600^2} = 0{\cdot}009166$ inch,

one hundred units (100,000) a spark of 91·66 inches,

a thousand units (1,000,000) „ 9166 inches = 764 feet nearly,

whereas a single cell would have a striking-distance of $\frac{1}{109{,}000{,}000}$ of an inch only. As far as our own experiments have gone the law has been confirmed; and although a million cells will probably never be made, a hundred thousand come within the range of experimental possibility.

January 13, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The following Paper was read:—

---

* *Postscript*, Jan. 8th.—A current was obtained with the negative point distant 5·1 inches from a positive plate 6 inches in diameter.

"On the Optical Deportment of the Atmosphere in reference to the Phenomena of Putrefaction and Infection." By JOHN TYNDALL, F.R.S. Received January 24, 1876.

The author refers in an Introduction to an inquiry on the decomposition of vapours and the formation of active clouds by light, whereby he was led to experiment on the floating matter of the air. He refers to the experiments of Schwann, Schröder, and Dusch, Schröder himself, to those of the illustrious French chemist Pasteur, to the reasoning of Lister and its experimental verification regarding the filtering-power of the lungs; from all of which he concluded, six years ago, that the power of developing life by the air, and its power of scattering light, would be found to go hand in hand. He thought the simple expedient of examining by means of a beam of light, while the eye was kept sensitive by darkness, the character of the medium in which their experiments were conducted could not fail to be useful to workers in this field. But the method has not been much turned to account; and this year he thought it worth while to devote some time to the more complete demonstration of its utility.

He also wished to free his mind, and if possible the minds of others, from the uncertainty and confusion which now beset the doctrine of "spontaneous generation." Pasteur has pronounced it "a chimera," and expressed the undoubting conviction that this being so it is possible to remove parasitic diseases from the earth. To the medical profession, therefore, and through them to humanity at large, this question is one of the last importance. But the state of medical opinion regarding it is not satisfactory. In a recent Number of the 'British Medical Journal,' and in answer to the question, "In what way is contagium generated and communicated?" Messrs. Braidwood and Vacher reply that, notwithstanding "an almost incalculable amount of patient labour, the actual results obtained, especially as regards the manner of generation of contagium, have been most disappointing. Observers are even yet at variance whether these minute particles, whose discovery we have just noticed, and other disease-germs, are always produced from like bodies previously existing, or whether they do not, under certain favourable conditions, spring into existence *de novo*."

With a view to the possible diminution of the uncertainty thus described, the author submits without further preface to the Royal Society, and especially to those who study the ætiology of disease, a description of the mode of procedure followed in this inquiry and the results to which it has led.

A number of chambers, or cases, were constructed, each with a glass front, its top, bottom, back, and sides being of wood. At the back is a little door which opens and closes on hinges, while into the sides are inserted two panes of glass, facing each other. The top is perforated in the middle by a hole 2 inches in diameter, closed air-tight by a sheet of india-rubber. This sheet is pierced in the middle by a pin, and through the pin-hole is passed the shank of a long pipette ending above in a small funnel. A circular tin collar, 2 inches in diameter and 1½ inch high, surrounds the pipette, the space between both being packed with cotton-wool moistened by glycerine. Thus the pipette, in moving up and down, is not only firmly clasped by the india-rubber, but it also passes through a stuffing-box of sticky cotton-wool. The width of the aperture closed by the india-rubber secures the free lateral play of the lower end of the pipette. Into two other smaller apertures in the top of the cupboard are inserted, air-tight, the open ends of two narrow tubes, intended to connect the interior space with the atmosphere. The tubes are bent several times up and down, so as to intercept and retain the particles carried by such feeble currents as changes of temperature might cause to set in between the outer and the inner air.

The bottom of the box is pierced, sometimes with two rows, sometimes with a single row of apertures, in which are fixed, air-tight, large test-tubes, intended to contain the liquid to be exposed to the action of the moteless air.

On the 10th of September the first case of this kind was closed. The passage of a concentrated beam across it through its two side windows then showed the air within it to be laden with floating matter. On the 13th it was again examined. Before the beam entered and after it quitted the case its track was vivid in the air, but within the case it vanished. Three days of quiet sufficed to cause all the floating matter to be deposited on the sides and bottom, where it was retained by a coating of glycerine, with which the interior surface of the case had been purposely varnished. The test-tubes were then filled through the pipette, boiled for five minutes in a bath of brine or oil, and abandoned to the action of the moteless air. During ebullition aqueous vapour rose from the liquid into the chamber, where it was for the most part condensed, the uncondensed portion escaping, at a low temperature, through the bent tubes at the top. Before the brine was removed little stoppers of cotton-wool were inserted in the bent tubes, lest the entrance of the air into the cooling chamber should at first be forcible enough to carry motes along with it. As soon, however, as the ambient temperature was assumed by the air within the case the cotton-wool stoppers were removed.

We have here the oxygen, nitrogen, carbonic acid, ammonia, aqueous vapour, and all the other gaseous matters which mingle more or less with the air of a great city. We have them, moreover, "untortured" by calcination and unchanged even by filtration or manipulation of any kind. The question now before us is, can air thus retaining all its gaseous mixtures, but self-cleansed from mechanically suspended matter, produce putrefaction? To this question both the animal and vegetable worlds return a decided negative.

Among vegetables experiments have been made with hay, turnips, tea, coffee, hops, repeated in various ways with both acid and alkaline infusions. Among animal substances are to be mentioned many experiments with urine; while beef, mutton, hare, rabbit, kidney, liver, fowl, pheasant, grouse, haddock, sole, salmon, cod, turbot, mullet, herring, whiting, eel, oyster have been all subjected to experiment.

The result is that infusions of these substances exposed to the common air of the Royal Institution laboratory, maintained at a temperature of from 60° to 70° Fahr., all fell into putrefaction in the course of from two to four days. No matter where the infusions were placed, they were infallibly smitten in the end. The number of the tubes containing infusions was multiplied till it reached six hundred, but not one of them escaped infection.

In no single instance, on the other hand, did the air which had been proved moteless by the searching beam prove itself, even when raised to temperatures varying from 80° to 90°, to possess the least power of producing Bacterial life or the associated phenomena of putrefaction. The power of developing such life in atmospheric air, and the power of scattering of light, are thus proved to be indissolubly united.

The sole condition necessary to cause these long-dormant infusions to swarm with active life is the access of the floating matter of the air. After having remained for four months as pellucid as distilled water, the opening of the back door of the protecting case, and the consequent admission of the mote-laden air, sufficed in three days to render the infusions putrid and full of life.

That such life arises from mechanically suspended particles is thus reduced to ocular demonstration.

Let us inquire a little more closely into the character of the particles which produce the life. Pour eau de Cologne into water, a white precipitate renders the liquid milky. Or, imitating Brücke, dissolve clean gum mastic in alcohol, and drop it into water, the mastic is precipitated, and milkiness produced. If the solution be very strong the mastic separates in curds; but by gradually diluting the alcoholic solution we finally reach a point where the milkiness disappears, the liquid assuming, by reflected light, a bright cerulean hue. It is, in point of fact, the colour of the sky, and is due to a similar cause, namely, the scattering of light by particles, small in comparison to the size of the waves of light.

When this liquid is examined by the highest microscopic power it seems as uniform as distilled water. The mastic particles, though innumerable, entirely elude the microscope. At right angles to a luminous beam passing among the particles they discharge perfectly polarized light. The optical deportment of the floating matter of the air proves it to be composed in part of particles of this excessively minute character. When the track of a parallel beam in dusty air is looked at horizontally through a Nicol's prism, in a direction perpendicular to the beam, the longer diagonal of the prism being vertical, a considerable portion of the light from the finer matter is extinguished. The coarser motes, on the other hand, flash out with greater force, because of the increased darkness of the space around them. It is among the finest ultra-microscopic particles that the author shows that the matter potential as regards the development of Bacterial life is to be sought.

But though they are beyond the reach of the microscope, the existence of these particles, foreign to the atmosphere but floating in it, is as certain as if they could be felt between the fingers or seen by the naked eye. Supposing them to augment in magnitude until they come, not only within range of the microscope, but within range of the unaided senses. Let it be assumed that our knowledge of them under these circumstances remains as defective as it is now—that we do not know whether they are germs, particles of dead organic dust, or particles of mineral matter. Suppose a vessel (say a flower-pot) to be at hand filled with nutritious earth, with which we mix our unknown particles, and that in forty-eight hours subsequently buds and blades of well-defined cresses and grasses appear above the soil. Suppose the experiment when repeated over and over again to yield the same unvarying result. What would be our conclusion? Should we regard those living plants as the products of dead dust or mineral particles, or should we regard them as the offspring of living seeds? The reply is unavoidable. We should undoubtedly consider the experiment with the flower-pot as clearing up our preexisting ignorance; we should regard the fact of their producing cresses and grasses as proof positive that the particles sown in the earth of the pot were the seeds of the plants which have grown from them. It would be simply monstrous to conclude that they had been "spontaneously generated."

This reasoning applies word for word to the development of *Bacteria* from that floating matter which the electric beam reveals in the air, and in the absence of which no Bacterial life has been generated. There seems no flaw in this reasoning; and it is so simple as to render it unlikely that the notion of Bacterial life developed from dead dust can ever gain currency among the members of a great scientific profession.

A novel mode of experiment has been here pursued, and it may be urged that the conditions laid down by other investigators in this field, which have led to different results, have not been strictly adhered to. To secure accuracy in relation to these differences, the latest words of a writer on this question, who has materially influenced medical thought both in this country and in America, are quoted. "We know," he says, "that boiled turnip- or hay-infusions exposed to ordinary air, exposed to filtered air, to calcined air, or shut off altogether from contact with air, are more or less prone to swarm with *Bacteria* and *Vibriones* in the course of from two to six days." Who the "we" are who possess this knowledge is not stated. The author is certainly not among the number, though he has sought anxiously for knowledge of the kind. He thus tests the statements in succession.

And first, with regard to filtered air. A group of twelve large test-tubes was caused to pass air-tight through a slab of wood. The wood was coated with cement, in which, while hot, a heated "propagating-glass" resembling a large bell-jar was imbedded. The air within the jar was pumped out several times, air filtered through a plug of cotton-wool being permitted to supply its place. The test-tubes contained infusions of hay, turnip, beef, and mutton—three of each, twelve in all. They are as clear and cloudless at the present moment as they were upon the day of their introduction; while twelve similar tubes, prepared at the same time, in precisely the same way, and exposed to the ordinary air, are clogged with mycelium, mould, and *Bacteria.*

With regard to the calcined air, a similar propagating-glass was caused to cover twelve other tubes filled with the same infusions. The "glass" was exhausted and carefully filled with air which had passed through a red-hot platinum tube containing a roll of red-hot platinum gauze. Tested by the searching beam, the calcined air was found quite free from floating matter. Not a speck has invaded the limpidity of the infusions exposed to it, while twelve similar tubes placed outside have fallen into rottenness.

The experiments with calcined air took another form. Six years ago it was found that, to render the laboratory air free from floating matter, it was only necessary to permit a platinum wire heated to whiteness to act upon it for a sufficient time. Shades containing pear-juice, damson-juice, infusions of hay and turnip, and water of yeast were freed from their floating matter in this way. The infusions were subsequently boiled and permitted to remain in contact with the calcined air. They are quite clear to the present hour, while the same infusions exposed to common air became mouldy and rotten long ago.

It has been affirmed by other writers on this question that turnip- and hay-infusions rendered slightly alkaline are particularly prone to exhibit the phenomena of spontaneous generation. This was not found to be the case in the present investigation. Many such infusions have been prepared, and they have continued for months without sensible alteration.

Finally, with regard to infusions wholly withdrawn from air, a group of test-tubes containing different infusions was boiled under a bell-jar first filled with filtered air, and from which the air was subsequently removed as far as possible by a good air-pump. They are now as pellucid as they were at the time of their preparation more than two months ago, while a group of corresponding tubes exposed to the laboratory air have all fallen into rottenness.

There is still another form of experiment on which great weight has been laid—that of hermetically sealed tubes. On the 6th of last April a discussion on the "Germ-Theory of Disease" was opened before the Pathological Society of London. The meeting was attended by many distinguished medical men, some of whom were profoundly influenced by the arguments, and none of whom disputed the facts brought forward against the theory on that occasion. The following important summary of these was then given by Dr. Bastian:—"With the view of settling these questions, therefore, we may carefully prepare an infusion from some animal tissue, be it muscle, kidney, or liver; we may place it in a flask whose neck is drawn out and narrowed in the blowpipe-flame, we may boil the fluid, seal the vessel during ebullition, and, keeping it in a warm place, may await the result, as I have often done. After a variable time, the previously heated fluid within the hermetically sealed flask swarms more or less plentifully with *Bacteria* and allied organisms."

Previous to reading this statement the author had operated upon 16 tubes of hay- and turnip-infusions, and upon 21 tubes of beef, mackerel, eel, oyster, oatmeal, malt, and potato, hermetically sealed while boiling, not by the blowpipe, but by the far more handy spirit-lamp flame. In no case was any appearance whatever of *Bacteria* or allied organisms observed. The perusal of the discussion just referred to caused the author to turn again to muscle, liver, and kidney, with a view of varying and multiplying the evidence. Fowl, pheasant, snipe, partridge, plover, wild duck, beef, mutton, heart, tongue, lungs, brains, sweetbread, tripe, the crystalline lens, vitreous humour, herring, haddock, mullet, codfish, sole, were all embraced in the experiments. There was neither mistake nor ambiguity about the result. One hundred and thirty-nine of the flasks operated on were submitted to the Fellows; and not one of this cloud of witnesses offered the least countenance to the assertion that liquids within flasks, boiled and hermetically sealed, swarm, subsequently, more or less plentifully with *Bacteria* and allied organisms.

The evidence furnished by this mass of experiments, that Dr. Bastian must have permitted errors either of preparation or observation to invade his work, is, it is submitted, very strong. But to err is human; and in an inquiry so difficult and fraught with such momentous issues, it is not error, but the persistence in error by any of us for dialectic ends that is to be deprecated. The author shows by illustrations the risks of error run by himself. On the 21st of October he opened the back door of a case containing six test-tubes filled with an infusion of turnip which had remained perfectly clear for three weeks, while three days sufficed to crowd six similar tubes exposed to mote-laden air with *Bacteria*. With a small pipette he took specimens from the pellucid tubes, and placed them under the microscope. One of them yielded a field of Bacterial life, monstrous in its copiousness. For a long time he tried vainly to detect any source of error, and was perfectly prepared to abandon the unvarying inference from all the other experiments, and to accept the result as a clear exception to what had previously appeared to be a general law. The cause of his perplexity was finally traced to the tiniest speck of an infusion containing *Bacteria*, which had clung by capillary attraction to the point of one of his pipettes.

Again, three tubes containing infusions of turnip, hay, and mutton were boiled, on the 2nd of November, under a bell-jar containing air so carefully filtered that the most searching examination by a concentrated beam failed to reveal a particle of floating matter. At the present time every one of the tubes is thick with mycelium and covered with mould. Here, surely, we have a case of spontaneous generation. Let us look to its history.

After the air has been expelled from a boiling liquid it is difficult to continue the ebullition without "bumping." The liquid remains still for intervals and then rises with sudden energy. It did so in the case now under consideration; and one of the tubes boiled over, the liquid overspreading the resinous surface in which the bell-jar was imbedded. For three weeks the infusions had remained perfectly clear. At the end of this time, with a view of renewing the air of the jar, it was exhausted, and refilled by fresh air which had passed through a plug of cotton-wool. As the air entered, two small spots of *Penicillium*, resting on the liquid which had boiled over, attracted attention. It was at once remarked that the experiment was a dangerous one, as the entering air would probably detach some of the spores of the *Penicillium* and diffuse them in the bell-jar. This was therefore filled very slowly, so as to render the disturbance a minimum. Next day, however, a tuft of mycelium was observed at the bottom of one of the three tubes, namely that containing the hay-infusion. It has by this time grown so as to fill a large portion of the tube. For nearly a month longer the two tubes containing the turnip- and mutton-infusions maintained their transparency unimpaired. Late in December the mutton-infusion, which was in dangerous proximity to the outer mould, showed a tuft upon its surface. The beef-infusion continued bright and clear for nearly a fortnight longer. The recent cold weather caused the author to add a third gas-stove to the two which had previously warmed the room in which the experiments are conducted. The warmth played upon one side of the bell-jar, causing currents within it; and the day after the lighting of the stove, the beef-infusion gave birth to a tuft of mycelium. In this case the small spots of *Penicillium* might have readily escaped attention; and had they done so we should have had three cases of "spontaneous generation" far more striking than many that have been adduced.

In further illustration of the danger incurred in this field of inquiry, the author refers to the excellent paper of Dr. Roberts on Biogenesis, in the Philosophical Transactions for 1874. Dr. Roberts fills the bulb of an ordinary pipette up to about two thirds of its capacity with the infusion to be examined. In the neck of the pipette he places a plug of dry cotton-wool. He then hermetically seals the neck, and dips the bulb into boiling water or hot oil, where he permits it to remain for the requisite time. Here we have no disturbance from ebullition and no loss by evaporation. The bulb is removed from the hot water and permitted to cool. The sealed end of the neck is then filed off, the cotton-wool alone interposing between the infusion and the atmosphere.

The arrangement is beautiful, but it has one weak point. Cotton-wool free from germs is not to be found, and the plug employed by Dr. Roberts infallibly contained them. In the gentle movement of the air to and fro, as the temperature changed, or by any shock, jar, or motion to which the pipette might be subjected, we have certainly a cause sufficient to detach a germ now and then from the cotton-wool which, falling into the infusion, would produce its effect. Probably also condensation occurred at times in the neck of the pipette, the water of condensation carrying back from the cotton-wool the seeds of life. The fact of fertilization being so rare as Dr. Roberts found it to be, is a proof of the care with which his experiments were conducted. But he did find cases of fertilization after prolonged exposure to the boiling temperature; and this caused him to come to the conclusion that under certain rare conditions spontaneous generation may occur. He also found that an alkalized hay-infusion was so difficult to sterilize that it was capable of withstanding the boiling temperature for hours without losing its power of generating life. The most careful experiments have been made with this infusion. Dr. Roberts is certainly correct in assigning to it superior nutritive power. But in the present inquiry five minutes' boiling sufficed to completely sterilize the liquid.

Summing up this portion of his inquiry, the author remarks that he will hardly be charged with any desire to limit the power and potency of matter in regard to life. But holding the notions he does upon this point, it is all the more incumbent on him to affirm that, as far as inquiry has hitherto penetrated, life has never been proved to appear independently of antecedent life.

Though the author had no reason to doubt the general diffusion of germs in the atmosphere, he thought it desirable to place the point beyond question. At Down Mr. Darwin and Mr. Francis Darwin, at High Elms Sir John Lubbock, at Sherwood, near Tunbridge Wells, Mr. Siemens, at Pembroke Lodge, Richmond Park, Mr. Rollo Russell, at Heathfield Park Miss Hamilton, at Greenwich Hospital Mr. Hirst, at Kew Dr. Hooker, and at the Crystal Palace Mr. Price kindly took charge of infusions, every one of which was invaded, many by astounding swarms of organisms. To obtain more definite insight regarding the diffusion of atmospheric germs a square wooden tray was pierced with 100 holes, into each of which was dropped a short test-tube. On October 23 thirty of these tubes were filled with an infusion of hay, thirty-five with an infusion of turnip, and thirty-five with an infusion of beef. The tubes with their infusions had been previously boiled, ten at a time, in an oil-bath. One hundred circles were marked on paper, so as to form a map of the tray, and every day the state of each tube was registered upon the corresponding circle. In the following description the term "cloudy" is used to denote the first stage of turbidity, distinct but not strong; the term "muddy" is used to denote thick turbidity.

One tube of the 100 was first singled out and rendered muddy. It belonged to the beef group, and it was a whole day in advance of all the other tubes. The progress of putrefaction was first registered on the 26th of October. The "map" then taken may be thus described:—

Hay.—Of the thirty specimens exposed one had become "muddy"—the seventh in the middle row reckoning from the side of the tray nearest a stove. Six tubes remained perfectly clear between this muddy one and the stove, proving that differences of warmth may be overridden by other causes. Every one of the other tubes containing the hay-infusion showed spots of mould upon the clear liquid.

Turnip.—Four of the thirty-five tubes were very muddy, two of them being in the row next the stove, one four rows distant, and the remaining one seven rows away. Besides these, six tubes had become clouded. There was no mould on any of the tubes.

Beef.—One tube of the thirty-five was quite muddy, in the seventh row from the stove. There were three cloudy tubes, while seven of them bore spots of mould.

As a general rule organic infusions exposed to the air during the autumn remained for two days or more perfectly clear. Doubtless from the first germs fell into them, but they required time to be hatched. This period of clearness may be called the "period of latency," and indeed it exactly corresponds with what is understood by this term in medicine. Towards the end of the period of latency the fall into a state of disease is comparatively sudden, the infusion passing from perfect clearness to cloudiness more or less dense in a few hours.

Thus the tube placed in Mr. Darwin's possession was clear at 8.30 A.M. on the 19th of October, and cloudy at 4.30 P.M. Seven hours, moreover, after the first record of our tray of tubes, a marked change had occurred. It may be thus described:—Instead of one, eight of the tubes containing hay-infusion had fallen into uniform muddiness. Twenty others had produced Bacterial slime, which had fallen to the bottom, every tube containing the slime being covered by mould. Three tubes only remained clear, but with mould upon their surfaces. The muddy turnip-tubes had increased from four to ten; seven tubes were clouded, while eighteen of them remained clear, with here and there a speck of mould on the surface. Of the beef, six were cloudy and one thickly muddy, while spots of mould had formed on the majority of the remaining tubes. Fifteen hours subsequent to this observation, viz. on the morning of the 27th of October, all the tubes containing hay-infusion were smitten, though in different degrees, some of them being much more turbid than others. Of the turnip-tubes, three only remained unsmitten, and two of these had mould upon their surfaces. Only one of the thirty-five beef-infusions remained intact. A change of occupancy, moreover, had occurred in the tube which first gave way. Its muddiness remained grey for a day and a half, then it changed to bright yellow-green, and it maintained this colour to the end. On the 27th every tube of the hundred was smitten, the majority with uniform turbidity, some, however, with mould above and slime below, the intermediate liquid being tolerably clear. The whole process bore a striking resemblance to the propagation of a plague among a population, the attacks being successive and of different degrees of virulence.

From the irregular manner in which the tubes are infected we may infer that, as regards *quantity*, the distribution of the germs in the air is not uniform. The singling out, moreover, of one tube of the hundred by the particular *Bacteria* that develop a green pigment shows that, as regards *quality*, the distribution is not uniform. The same absence of uniformity was manifested in the struggle for existence between the *Bacteria* and the *Penicillium.* In some tubes the former were triumphant; in other tubes, of the same infusion, the latter was triumphant. It would seem also as if a want of uniformity as regards *vital vigour* prevailed. With the selfsame infusion the motions of the *Bacteria* in some tubes were exceedingly languid, while in other tubes they resembled a rain of projectiles, being so rapid and violent as to be followed with difficulty by the eye. Reflecting on the whole of this, the author concludes that the germs float through the atmosphere in groups or clouds, with spaces more sparsely filled between them. The touching of a nutritive fluid by a Bacterial cloud would naturally have a different effect from the touching of it by the interspace between two clouds. But as in the case of a mottled sky the various portions of the landscape are successively visited by shade, so, in the long run, were the various tubes of the tray touched by the Bacterial clouds, the final fertilization or infection of them all being the consequence. The author connects these results with the experiments of Pasteur on the non-continuity of the cause of so-called spontaneous generation, and with other experiments of his own [*].

---

[*] In hospital practice the opening of a wound during the passage of a Bacterial cloud would have an effect very different from the opening of it in the interspace between two clouds. Certain caprices in the behaviour of dressed wounds may possibly be accounted for in this way.

Under the heading "Nothing new under the Sun," Prof. Huxley has just sent me the following remarkable extract:—"Uebrigens kann man sich die in der Atmosphäre schwimmenden Thierchen wie Wolken denken, mit denen ganz leere Luftmassen, ja

On the 9th of November a second tray containing one hundred tubes, filled with an infusion of mutton, was exposed to the air. On the morning of the 11th six of the ten nearest the stove had given way to putrefaction. Three of the row most distant from the stove had yielded, while here and there over the tray particular tubes were singled out and smitten by the infection. Of the whole tray of one hundred tubes, twenty-seven were either muddy or cloudy on the 11th. Thus, doubtless, in a contagious atmosphere, are individuals successivly struck down. On the 12th all the tubes had given way, but the differences in their contents were extraordinary. All of them contained *Bacteria*, some few, others in swarms. In some tubes they were slow and sickly in their motions, in some apparently dead, while in others they darted about with rampant vigour. These differences are to be referred to differences in the germinal matter, for the same infusion was presented everywhere to the air. Here also we have a picture of what occurs during an epidemic, the difference in number and energy of the Bacterial swarms resembling the varying intensity of the disease. It becomes obvious from these experiments that of two individuals of the same population exposed to a contagious atmosphere, the one may be severely, the other lightly attacked, though the two individuals may be as identical as regards susceptibility as two samples of one and the same mutton-infusion. Experiments with other trays are described in the paper, and calculations are made regarding the number of germs held in suspension by the air.

The author traces still further the parallelism of these actions with the progress of infectious disease. The 'Times' of January 17 contained a letter on typhoid fever, signed "M.D.," in which occurred the following remarkable statement:—"In one part of it [Edinburgh], congregated together and inhabited by the lowest of the population, there are, according to the Corporation return for 1874, no less than 14,319 houses or dwellings—many under one roof, on the 'flat' system —in which there are no house connexions whatever with the street-sewers, and, consequently, no water-closets. To this day, therefore, all the excrementitious and other refuse of the inhabitants is collected in pails or pans, and remains in their midst, generally in a partitioned-off corner of the living-room, until the next day, when it is taken down to the streets and emptied into the Corporation carts. Drunken and vicious though the population be, herded together like sheep, and with the filth collected and kept for 24 hours in their very midst, it is a remarkable fact that typhoid fever and diphtheria are simply unknown in these wretched hovels."

This case has its analogue in the following experiment, which is re-

---

ganze Tage völlig reinen Luftverhältnisse wechseln." (Ehrenberg, "Infusionsthierchen," 1838, p. 525.) The coincidence of phraseology is surprising, for I knew nothing of Ehrenberg's conception. My "clouds," however, are but small miniatures of his.

presentative of a class:—On the 30th of November a quantity of animal refuse, embracing beef, fish, rabbit, hare, was placed in two large test-tubes opening into a protecting-chamber containing six tubes. On December 13, when the refuse was in a state of noisome putrefaction, infusions of whiting, turnip, beef, and mutton were placed in the other four tubes. They were boiled and abandoned to the action of the foul "sewer-gas" emitted by their two putrid companions. On Christmas-day these four infusions were limpid. The end of the pipette was then dipped into one of the putrid tubes, and a quantity of matter, comparable in smallness to the pock-lymph held on the point of a lancet, was transferred to the turnip. Its clearness was not sensibly affected at the time; but on the 26th it was turbid throughout. On the 27th a speck from the infected turnip was transferred to the whiting; on the 28th disease had taken entire possession of the whiting. To the present hour the beef- and mutton-tubes remain as limpid as distilled water. Just as in the case of the living men and women in Edinburgh, no amount of fetid gas had the power of propagating the plague as long as the organisms which constitute the true contagium did not gain access to the infusions.

The universal prevalence of the germinal matter of *Bacteria* in water has been demonstrated with the utmost evidence by the experiments of Dr. Burdon Sanderson. But the germs in water are in a very different condition, as regards readiness for development, from those in air. In water they are thoroughly wetted, and ready, under the proper conditions, to pass rapidly into the finished organism. In air they are more or less desiccated, and require a period of preparation more or less long to bring them up to the starting-point of the water-germs. The rapidity of development in an infusion infected by either a speck of liquid containing *Bacteria* or a drop of water is extraordinary. On the 4th of January a thread of glass almost as fine as a hair was dipped into a cloudy turnip-infusion, and the tip only of the glass fibre was introduced into a large test-tube containing an infusion of red mullet. Twelve hours subsequently the perfectly pellucid liquid was cloudy throughout. A second test-tube containing the same infusion was infected with a single drop of the distilled water furnished by Messrs. Hopkin and Williams; twelve hours also sufficed to cloud the infusion thus treated. Precisely the same experiments were made with herring with the same result. At this season of the year several days' exposure to the air are needed to produce the same effect. On the 31st of December a strong turnip-infusion was prepared by digesting in distilled water at a temperature of 120° Fahr. The infusion was divided between four large test-tubes, in one of which it was left unboiled, in another boiled for five minutes, and in the two remaining ones boiled and after cooling infected with one drop of beef-infusion containing *Bacteria*. In twenty-four hours the unboiled tube and the two infected ones were cloudy, the unboiled tube being the most turbid of the three. The infusion here was peculiarly limpid after digestion; for turnip it was quite exceptional, and no amount of searching with the microscope could reveal in it at first the trace of a living *Bacterium*; still germs were there which, suitably nourished, passed in a single day into Bacterial swarms without number. Five days have not sufficed to produce an effect approximately equal to this in the boiled tube, which was uninfected but exposed to the common laboratory air.

There cannot, moreover, be a doubt that the germs in the air differ widely among themselves as regards *preparedness* for development. Some are fresh, others old; some are dry, others moist. Infected by such germs the same infusion would require different lengths of time to develop Bacterial life. This remark applies to and probably explains the different degrees of rapidity with which epidemic disease acts upon different people. In some the hatching-period, if it may be called such, is long, in some short, the differences depending upon the different degrees of preparedness of the contagium.

The author refers with particular satisfaction to the untiring patience, the admirable experimental skill, the veracity in thought, word, and deed displayed throughout this first section of a large and complicated inquiry by his assistant, Mr. John Cottrell, who was zealously aided by his junior colleague, Mr. Frank Valter.

February 4, 1876.—J. T.

January 20, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Right Hon. Lord Aberdare and the Right. Hon. George Sclater-Booth, whose Certificates had been suspended, as prescribed by the Statutes, were balloted for and elected Fellows of the Society.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Certain cases of Electromotive Force sustained by the Action of Electrolytes on Electrolytes." By J. Hopkinson. Communicated by Sir W. Thomson. Received November 29th, 1875.

In the following experiments the electromotive force was observed by a quadrant electrometer arranged for maximum sensibility; the connexions were made through the reversing-key; and, excepting the time observations for polarization, the readings were made twice at least on each side of the zero-point. A single Daniell's element gave 105 divisions deflection each way, so that in the following the unit of electromotive force is $\frac{1}{105}$ the electromotive force of Daniell's element. In all cases the electrodes were platinum wires dipping into the fluid under examination.

In the experiments on polarization the circuit was readily closed for a specified time by bringing the platinum wires into contact, and broken by releasing them; the electromotive force could then be observed at any instant after breaking the circuit.

I. Strong sulphuric acid was poured into a test-tube, which dipped into a porcelain crucible containing caustic potash. Thus the acid and alkali were separated by the glass of the tube. Platinum electrodes dipped into the two liquids. Electromotive force of 70 divisions was observed, the acid being positive. The crucible was heated by a spirit-lamp till the potash began to boil, the electromotive force increased to 153. The lamp was removed and the crucible allowed to cool; the electromotive force steadily diminished to 78 in half an hour. The tube was then discharged and insulated to observe the rate at which the charge developed.

	E. F.
15 seconds after insulation,	67
30 " "	69
60 " "	69

II. The tube, crucible, and wire were thoroughly washed with cold water and replaced in position, but with water in place of both the acid and the alkali. The inside of the tube where the acid had been was now *negative*. E. F.=16½. Heating to boiling the deflection increased to 150 divisions, but sank to 2 on cooling.

III. The test-tube contained potash and dipped into water in the crucible. When cold, E. F.=33, the potash being negative; when heated to boiling, E. F.=36½.

IV. The tube contained strong sulphuric acid and dipped into water; a deflection of less than three divisions was observed. When heated till the water boiled, the reading was 35. After cooling the deflection decreased to 5.

V. The test-tube was removed and a small porcelain crucible introduced in its place; sulphuric acid was poured into the outer crucible, potash into the inner; platinum electrodes dipped into the liquids. On heating till the potash boiled, the electromotive force rose as high as 162. The decrease of the electromotive force as the liquids cooled was then observed.

Time in minutes.	E. F.	
0	155	boiling.
32	94	still warm.
91	88	quite cold.
181	88	

The author supposed these effects to be due to electrolytic action through the glass, not suspecting the true cause, excepting in V. But Sir William Thomson pointed out to him that the rate of development of the charge was greater than could occur *through* a substance of the low conductivity of the most conducting glass, and that the circuit must have been completed by conduction through a film of moisture on the surface of the glass. The next two experiments prove this to be the case.

VI. Drops of strong sulphuric acid and of caustic potash were placed on a sheet of common window-glass, previously carefully cleaned, but exposed to the air of the room. Platinum electrodes, dipping into each drop, communicated with the electrometer.

1. Drops half an inch apart, E. F. = 47.

2. The drops were connected by a thin trail of alkali drawn from the drop of alkali; E. F. = 105.

3. Drops 5 inches apart, two minutes being allowed for the charge to develop; E. F. = 12.

4. A trail was drawn halfway from one drop to the other; E. F.=31.

5. The trail of liquid was continued till but ¼ inch of clear glass separated the liquids; E. F. = 43.

6. The connecting trail was completed from one drop to the other; E. F. = 70. It was observed that the potash trail had dried up, leaving a line of alkali between the drops.

VII. A dry chip of deal 6 inches long was split at each end, and a platinum wire let into each slit; the two wires were moistened with sulphuric acid and potash respectively at the points of contact with the wood; E. F. = 43.

VIII. Clean platinum wires were let into slits in a second dry chip of deal 12 inches long; these were connected for twenty minutes with the poles of a battery of two Daniell's elements, and then detached and connected through the reversing-key with the electrometer. As was expected an electromotive force opposite to that of the battery was observed, at first amounting to 33 divisions.

These experiments show that imperfect insulation, such as glass exposed to the air or wood, may cause errors in electrical experiments, not merely by leakage, but by introducing unknown electromotive forces, arising either from the imperfect insulators connecting different liquids, or from electrolytic polarization after a current has for some time been creeping through or over the surface of the insulators.

Several experiments were then tried on the direct action of liquids on liquids; two only are given here, because determinations have been made by other methods by Becquerel and others.

IX. In a previous experiment a plug of moist sand had been rammed into the bend of a U-tube, and strong sulphuric acid and caustic potash poured into the limbs. When this tube was washed out, it was found that a plug of sulphate of potash and sand $\frac{3}{16}$ inch thick had formed across the middle of the bend. Strong sulphuric acid and potash were again poured into the limbs, and were now only separated by a thin plug of sulphate of potash. Platinum electrodes dipped into the liquids. Electromotive force 139. The circuit was closed for ten minutes.

		E. F.
14 seconds	after insulation,	31
20 „	„	39
40 „	„	44
1 minute	„	48
3 minutes	„	74
5 „	„	89
10 „	„	98
20 „	„	105
65 „	„	119

The wires were again connected and the circuit left closed for about twenty-four hours. It was found that the plug had extended for about half an inch on the side of the sulphuric acid by the formation of crystals of sulphate of potash, but had not apparently changed where it was in contact with the potash.

X. A similar plug was formed in a second tube. Into one limb sulphuric acid, with a small quantity of permanganate of potash, was poured, into the other caustic potash: E. F. = 178. Circuit was closed for ten minutes.

		E. F.
10 seconds	after insulation,	90
20 „	„	110
40 „	„	123
1 minute	„	128
3 minutes	„	138
9 „	„	148
19 „	„	150

II. "On Reversed Photographs of the Solar Spectrum beyond the Red, obtained on a Collodion Plate," in a Letter to Prof. Stokes. By Captain J. Waterhouse, Assistant Surveyor-General of India. Communicated by Professor Stokes. Received November 29, 1875.

Surveyor-General's Office,
Calcutta, November 5, 1875.

My dear Sir,—I have the pleasure to send you, by Overland Parcel Post, for presentation to the Royal Society, two photographs on glass of the solar spectrum, showing the extreme red rays below A, obtained on a dry collodion plate prepared with bromide of silver stained with a blue dye [*], and exposed to diffused daylight for a moment before being placed in the camera to receive the image of the spectrum. I also send another plate, also a dry bromide plate, stained with the same blue dye, and prepared at the same time and in the same manner as the other plates, but not exposed to light and quite free from fog; and you will observe that on this there is no trace of the reversed action in the red rays, and that the direct action only extends slightly below C.

This power of the red rays of the spectrum to neutralize the action of white light on sensitive daguerreotype plates was frequently noticed by Sir J. Herschel, Draper, Fizeau, Claudet, and other daguerreotypists about thirty years ago, but, so far as I can ascertain, it has never been observed on collodion plates. As collodion has so many advantages over the daguerreotype, it seems probable that this new extension of an old principle may have an important practical application in spectroscopic photography, particularly for the mapping of a part of the spectrum in which eye-observations can only be made with difficulty and under favourable circumstances.

The apparatus used for obtaining two of these photographs consisted of a Browning's chemical spectroscope, fitted with a very fine flint prism of 60°, and used in conjunction with one of Dallmeyer's rapid rectilinear lenses of 30″ focus. The rays of the sun were collected from a 9″ heliotrope, worked by hand, and thrown on the slit by means of a condensing-lens of 3″ diameter and 25″ focus. The aperture of the slit varied from ·003 to ·005, as marked on the plate.

The other single photograph was taken with a five-prism direct-vision spectroscope, by the same maker, also attached to the rapid rectilinear lens, and with the same arrangement of heliotrope and condenser.

The plates were prepared with a bromized collodion made by Rouch, sensitized in a bath of pure nitrate of silver at 16 per cent., then well washed in several changes of water and treated with a watery solution of the blue dye, again washed to remove the superfluous colour, and then dried. The colour of the prepared plates when dry was a light lavender. The development was by the alkaline method, followed by an intensification with acid, silver, and pyrogallic acid. Before being placed in the dark slide, the plates on which the extreme red rays are shown received a momentary exposure to diffused daylight by quickly opening and shutting the window of the dark room.

It will be observed that the best results have been obtained with long exposures of 30 or 40 minutes; and it is also necessary to work with rather an open slit, which injures the definition very much, so that the details of the many lines which I have ascertained to exist in the portion of the spectrum below A are not at all distinct; but it is possible that means may be found for obtaining better results with moderate exposure and a fine slit; and I hope to be able to continue the investigation with this object in view.

---

[*] I enclose a specimen of the dye. I do not know its chemical name, but it appears to belong to the aniline or some analogous series, and was obtained in the native market here. Dissolved in alcohol it is of a fine deep blue, but the addition of water changes the tint to a rich violet or purple.

[I have compared the specimen, as to its absorption-spectrum and the action of reagents, with authentic aniline blue, and the two appear to be identical.—G. G. S.]

I have not been able yet to ascertain in what manner the blue dye acts; but that it plays an important part in obtaining the results is evident from the fact that on a dry bromide plate unstained the reversing effect of the red rays is not observed. I was led to use it from observing, during the course of an investigation of Dr. H. Vogel's important discovery of the effect of certain dyes on the sensibility of dry bromide-of-silver plates to the less refrangible rays, that on plates stained with aniline red, orange, green, and blue, the A and other lines in the red were often visible reversed; and there were traces of reversed action below A, but most markedly on the plates stained with the particular blue dye referred to. As I had not observed it on the plain unstained bromide plates, I attributed the effect to the action of the dyes, overlooking the fact that the plates were all slightly fogged. On repeating the experiments with the blue-stained plates, prepared in a purified bath and very free from fog, the reversed action was not perceptible; and recollecting the old daguerreotype experiments, the idea suggested itself of trying whether it could be obtained by means of the preliminary exposure to light.

On examining my spectrum negatives, I find that the same reversing action in the red is also to be traced on a few plates prepared with bromoiodized collodion, exposed wet and developed with the ordinary iron developer; but further experiments are required before I can ascertain whether good results can be obtained in this manner. The effect of staining the dry bromide films with other dyes has also to be investigated.

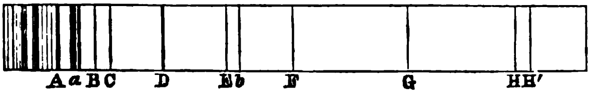
I would further draw your attention to the reversal of the blue and violet rays between H and F. I have observed this effect on all dry bromide plates, whether stained or unstained. It appears to be caused chiefly by overexposure, but may also be partly due to the action of the alkaline developer. On some plates it is more distinct and of greater extent than on others. I am scarcely sufficiently acquainted with the subject to venture on an explanation of this action of the blue rays, but may remark that they would appear to lose by long and excessive action the decomposing power they first exert on the bromide-of-silver film, and to exercise instead the neutralizing and bleaching action of the red rays. On the single photograph this reversed action of both sets of rays is well illustrated, and the whole spectrum is reversed from H to below A, the minimum of action being about F.

Should you consider the subject of sufficient interest, I trust you will do me the favour of bringing this communication to the notice of the Society; and I need not say that I shall be exceedingly glad of any suggestions for improving the method and utilizing it in making systematic observations of any points which may be elucidated by its means.

Received December 6, 1875.

Surveyor-General's Office,
Calcutta, November 12, 1875.

Dear Sir,—In continuation of my letter of last week I enclose a sketch of the lines in the extreme red rays, as nearly as I can make them out, from one of the photographs I have taken in the manner described, and the only one in which I have obtained the lines so clearly. It was taken at 1.48 p.m. on the 8th October (just at the close of our rainy season) with an exposure of 15 minutes, the same arrangement of spectroscope being used as for taking the two negatives I sent you last mail.



I have since writing made a successful experiment in obtaining reversed negatives on insolated, blue-stained, dry bromized collodion plates by means of the reversing action of the red rays passing through ruby glass, and also on similar plates prepared with bromized collodion coloured a bright yellow with tincture of annatto. I have also reason to believe that it will not be impossible to obtain the same reversing action through *blue* glass; but further trials are requisite.

I may also add that I have found that dry bromide plates prepared with the collodion containing annatto are more highly sensitive to the whole spectrum than any others; so that I have obtained the C, B, *a*, and A lines quite distinctly on such plates *unreversed*, and also one line below A at about the same distance from it as *a*.

III. "Report of the Meteorological Committee to the President and Council of the Royal Society on the Work done in the Meteorological Office since their appointment in 1866 to December 31, 1875."

The business of the Office will be reviewed under the three heads into which it is subdivided, and which are as follows:—

I. Ocean Meteorology.
II. Weather Telegraphy.
III. Land Meteorology of the British Islands.

I. Ocean Meteorology.

The most important task of the Committee at its first institution was to examine and to take stock of all the instruments and materials for work existing in the Office.

Inquiry was made into the actual condition and employment of all instruments outstanding on the books, whereby several were recovered, and several proved to be non-existent. Since 1867 no instruments have been supplied, except for the public service.

The books in the Office, which have been kept since 1854, enable us to trace the history and corrections of every instrument which has ever been purchased.

The entire store of documents in the Office was carefully examined by Capt. Toynbee; those that were worthless were set aside, and in the remainder the quality of each element which they contained was marked.

The Office then resumed the supply of instruments to observers at sea, and reorganized the agencies at certain ports. These agencies are paid according to results. The outcome of these operations is shown in the Annual Reports.

Among the most important benefits to the science attributable to the action of the Committee has been the great improvement in the quality of the logs sent in, owing to the care taken to select observers.

The following figures show the total number of *logs*, and the number of first-class *logs*, classed "*excellent*," which have been received each year from the *Mercantile Marine* since the management of the Office has been under the Meteorological Committee.

Year.	Total No. of Logs received.	No. of Excellent Logs.	°/₀ of Excellent Logs.	Year.	Total No. of Logs received.	No. of Excellent Logs.	°/₀ of Excellent Logs.
1867.	21	7	33	1871.	150	72	48
1868.	50	10	20	1872.	110	64	58
1869.	67	21	31	1873.	92	52	57
1870.	81	41	51	1874.	88	56	64

The marked improvement shown in the last few years is doubtless entirely due to a thoroughly systematic supervision by Captain Toynbee of all logs received. In every case where improvement is considered necessary, and reasonably practicable, the captain responsible for the log has been communicated with, and in many cases induced to call at the Office for a personal interview.

The high percentage of excellent logs in recent years is in no way to be attributed to a lower standard of excellence being used; on the contrary, the standard of excellence may be considered to have increased rather than to have diminished.

It seems that greater weight should be attached to the relative values above, from the fact that the classification has been carried out by the same person throughout the whole period, so that the method of classification would doubtless be uniform.

The continuity of the observations and the hours at which observations have been recorded are of late years more in accordance with the generally accepted principles for the calculation of mean results.

At the same time it should be remarked that there is great difficulty in securing a supply of observers, and that it is in contemplation to relax in some measure the rigour of the tests applied to the observations.

As regards our Methods of Operation and our Instructions for keeping the Log, the latter were printed in full by the recent Maritime Conference held in London in 1874, and an extract of the Methods was also given.

The works published by the Office in this Department have been:—

O. 4. Charts of Surface Temperature for the South Atlantic, Monthly, and for 5° Squares, representing the Observations from Board of Trade Registers, and also results for smaller spaces from the Dutch Records published in 'Ondersoekingen met den Zeethermometer.'

O. 11. Contributions to our Knowledge of the Meteorology of Cape Horn and the West Coast of South America. Monthly tables, charts, and summaries of observations from 5° Squares; materials collected by Admiral FitzRoy, and supplemented by data from other sources and for other localities. This contribution is of some importance as preliminary to a more complete investigation into the meteorology of that region. Among the points brought out by it are the existence of an area of high barometrical pressure on the Tropic of Capricorn in the South Pacific, like those on the two tropics in the Atlantic, and also the fact that sea surface-temperature ranges *above* that of the air, even in the region of Humboldt's Current.

O. 12. The Currents and Surface-Temperature in the North Atlantic, 0°–40° N., giving, for 2½° Squares, Monthly Charts for Direction and Velocity, and for Temperature, and an Annua Chart.

These were the first monthly current-charts which were published, excepting those of Lieut. Fergusson for the Indian Ocean, &c.

O. 13. On the Weather of the North Atlantic in February 1870. This paper will be noticed under Weather Telegraphy.

O. 18. Contributions to our Knowledge of the Meteorology of the Antarctic Regions. This was a discussion, according to date and locality, of the materials contained in the logs of H.M.S. 'Erebus' and 'Terror' in 1840–43, and threw much additional light on the meteorological conditions of that region of the globe.

O. 20. Charts of Meteorological Data for Square 3, lat. 0°–10° N., long. 20°–30° W., and Remarks to accompany the Monthly Charts, 319 pp.

The charts show the means for all the elements for 2° squares, and consequently the best routes across the equator in each month; and the remarks contain extracts relating to currents, clouds, sea temperature, specific gravity, wind, weather, natural history, &c.

In an Appendix is given a Discussion of Four-hourly means of the Barometer, and Air and Sea Temperature for each Month and for the Year in the Northern and Southern Halves of the Square, from which have been calculated the diurnal-range corrections for the district.

This is the most elaborate paper ever published for any portion of the ocean; and the large relative proportion of labour bestowed on the district is justified by the considerations that the amount of material existing for it is quite exceptional, and that it lies on the highroad between the North and South Atlantic, and is the meeting-place of the two trade-winds.

The meteorologist thus finds the materials for a study of the conditions of wind, ocean-currents, weather, &c. in a region where two great currents of air are always meeting, with information as to the diurnal march of pressure and temperature in the region of the equator and at sea; while the sailor finds, in the monthly charts, diagrams of what he may expect to encounter on his passage through the Square at any season; and in the text containing the explanations he finds a discussion of the entire mass of information, and, as a final conclusion, advice as to the best route for crossing the Line in each month.

The public will, however, be in a much better position to judge of the work of the Office when the Charts, &c. now in the press, for the nine squares (lat. 10° S.–20° N., long. 10°–40° W.), of which Square 3 forms the centre, are published. In these charts, as dealing with a larger area and stretching from shore to shore of the Atlantic, are given not only charts of the same character as those above described (though for larger areas, owing to comparative deficiency of material), but also diagrams showing the direction of wind in connexion with atmospherical pressure and temperature, and of ocean-currents with sea-temperature.

There is also given a tabular statement contrasting the specific gravity of the sea in the easterly [going] or "Guinea" current and in the westerly currents due to each trade-wind.

In the Remarks copious quotations are made from the Logs in relation to the various phenomena which come under the seaman's observation, such as the weather, the wind, the motion of the clouds in relation to the lower wind, the direction of the swell, the colour and luminosity of the sea, and the current rips; as well as information relating to the birds, fish, and insects that are met with, and the variation from month to month of the localities in which they are seen, and also appearances of submarine volcanic action in certain localities.

By these investigations it is believed that important light has been thrown on several subjects of general as well as of special interest.

1. As to the tendency of the wind blowing along a coast-line to draw round a cape.
2. As to the relation of the surface-temperature and the currents of the sea near the equator to the westerly gales of high northern and southern latitudes in their respective winters; as to the dipping of a cold current under a warm one, and the variation with the seasons in the amount of easterly current near the equator.
3. As to a probable relation between the well-known rollers of Ascension and St. Helena and the winter gales of the North Atlantic, and a corresponding relation of the rollers on the west coast of Africa to the winter gales of high southern latitudes.
4. As to the remarkable difference in direction of the wind in December on opposite sides of the Cape-Verde Islands, being *easterly* to the westward and *north-north-east* to the eastward of them.
5. As to the remarkable unsteadiness and gustiness of the north-east trade with a clear sky in Square 40 (lat. 10°–20° N., long. 30°–40° W.), in certain months.
6. As to the difference between the wind and weather of Square 303 (lat. 0°–10° S., long. 30°–40° W.), off Cape St. Roque and its neighbourhood, and those of the Squares lying to the eastward of that point, more especially in regard of the fact that in certain months the wind in Square 303, during the squalls which frequently occur, constantly changes between south-east and south-south-west in such a way that the seaman finds very great difficulty in working to the southward if he approaches too near the Brazilian coast.
7. As to the relation of the upper currents of the atmosphere (indicated by cloud motion) to the lower winds—*e.g.*, how the equatorial margin of one Trade appears to rise above the edge of the other Trade, how the upper clouds move from the north-east over the south-west monsoon on the coast of Africa, and how sometimes clouds move from the south-east, the sky looking very heavy towards that quarter, while the surface wind is steady from south-west.
8. As to the relation between heavy dew and sea-temperature in some

parts and at certain seasons, and the connexion between mist (haze) and African dust.

9. The diagrams give a picture of Maury's "wedge-shaped doldrums" which any sailor can understand, and the remarks show the weather experienced in them.

In these discussions the object of the Meteorological Office has been to determine the meteorological statistics of limited portions of the ocean in each separate month by means of results obtained by discussion of original observations extracted from the logs in the Office.

The scope of these publications is consequently different from that of the charts published by the Admiralty, which aim at giving a general view of what may be expected at each season (three-monthly period) over the Atlantic Ocean, as in the "Pilot" Charts, or the whole navigable globe, as in the "Wind and Current" Charts.

Of the two investigations in question Capt. Toynbee has given popular accounts in papers read before the United Service Institution (in 1873) and before the British Association (in 1875) respectively.

The Office having thus completed the examination of the district close to the equator in the Atlantic Ocean, about the most important and interesting to the navigator and meteorologist of any region in the world, has commenced the investigation of the meteorology of another great district lying on the highroad between Europe and the Indian and Australian seas, that of the Cape of Good Hope, which will be prosecuted in due course, the question of the best method of dealing with that district being under consideration.

Another inquiry of considerable interest, of the same nature as that noted as O. 13, is being instituted into the wind and weather of the North Atlantic during the month of August 1873. For this the Office has obtained the loan of 280 logs, as will be mentioned later on.

While thus working at its own materials the Office has not been neglectful of foreign publications of value bearing on Ocean Meteorology.

Three of these have been specially published, in addition to the reproduction of the Dutch Sea-Temperature Observations for the Atlantic, which have been already mentioned.

These three are:—

N. O. 4. Routes for Steamers from Aden to the Straits of Sunda and back. Translated from a paper by Lieut. J. E. Cornelissen, of the Royal Meteorological Institute, Utrecht.

N. O. 5. On the Winds, &c. of the North Atlantic along the Tracks of Steamers between Europe and America. Translated from a paper by Herr von Freeden, of the Deutsche Seewarte, Hamburg.

N. O. 7. Notes on the Form of Cyclones in the Southern Indian Ocean. Reprint of a paper by C. Meldrum, M.A., F.R.A.S., Secretary of the Meteorological Society of the Mauritius.

With reference to the Recommendations contained in the Report of the Committee of Inquiry (1866) in relation to the subject of Ocean Meteorology (p. 15 of their Report) it may be said:—

a. As regards the works and discussions of observations now in progress.	Recommendations have been carried out in principle, but with such variations in detail as appeared necessary.
b. As regards the collection of further observations.	Recommendations have been carried out as closely as it was found feasible to do so.
c. As regards the method of extracting the observations.	The plan of loose cards suggested was tried for a certain time, but was subsequently given up for another (described in the Report of the Meteorological Committee for 1867, pp. 8 and 60) which experience showed to be preferable.
d. As regards the method of discussing and tabulating the results of observations when extracted.	These recommendations have not been fully carried out; on the one hand the work has been conducted to a much greater degree of minuteness and over more limited areas than was contemplated in the report, such a plan being considered to afford results of a more valuable character in the interests of navigation. On the other hand, with every desire to carry out the recommendations of the Report, it has not been found practicable to *weight* the observations, and consequently to assign *the degree of probable precision* to the results.
e. As regards the publication of meteorological results.	The recommendations have been carried out in principle but not to the letter. The publications of the Office have been more methodical than those criticised in the report.
f. As regards the publication of other results useful to navigation.	The recommendations as regards communication of hydrographical notices to the Admiralty have been fully carried out. The report, however, did not apparently contemplate the publication of any data in the form of charts by the Meteorological Office; it was, however, considered by the Meteorological Committee that for certain purposes, as indicated by the foregoing statement, the form of a chart was preferable to ordinary letterpress.

II. WEATHER TELEGRAPHY.

The first action prior to the resumption of the issue of storm-warnings was the inspection of the stations.

This has been annually carried out ever since. Much that was objectionable has been gradually improved, and at present 16 out of the 29 stations are provided with the Stevenson's thermometer-screen.

Observers have been changed from time to time, so that at present only 12 are telegraph clerks, and all are distinctly and immediately responsible to the Office.

The Office may fairly claim for its service a higher degree of scientific accuracy and completeness than exists in any *at present* in operation in Europe. It must always be remembered that, as a rule, telegraphic stations are not likely to be good stations for general climatology, the conditions which determine the choice of locality being widely different in the two cases. It seems therefore less incumbent on the Office to publish means for temperature, &c. for these stations than would appear to have been held by some authorities, to judge from the evidence on the subject laid before the recent Science Commission.

A difficulty in dealing with Weather Telegraphy is to be found in the frequency of telegraphic errors, which renders any absolute dependence on figures received by telegraph impossible. Some idea of the extent to which this evil affects the scientific prosecution of weather study and interferes with the formation of correct views of the essential facts with the promptitude that is required for the practical application of the deduced results—the issue of warnings to the coasts—may be gathered from the fact that in the case of one single station, Oxford, 49 errors were detected (on receipt of the original MS. messages) in the space of 18 months, which were all proved to be due to inaccurate transmission, and were in addition to a considerable number which had been discovered at first inspection of the telegrams (owing to the glaring discrepancy of the reports from those of adjacent stations), and had been corrected by repetition of the message.

This number gives about 32 errors per annum; so that on this hypothesis there would be 32 × 29 or 928 errors from British stations coming in every year, which it is apparently impossible to detect by simple inspection of the telegrams.

Of errors in barometrical and thermometrical readings as received by telegraph and suspected from their discrepancy *inter se*, the Office discovers more than 1000 every year, frequently eliciting a correction by repetition of the telegram and correspondence with the observers.

The following memorandum shows the present condition of the Weather Service:—

A Comparison of the "Daily Weather Report," as it appeared at the time of the Report of the Committee of Inquiry in 1866, with the same Report as now published.

Contents.

1866.	1875.
1.—REPORTS GIVEN, FOR 8 A.M., FROM 20 STATIONS.	1.—REPORTS GIVEN, FOR 8 A.M., FROM 51 STATIONS.
16 in the United Kingdom. 4 on the Continent. Countries represented being— British Isles, exclusive of the Shetlands, Hebrides, and Scilly. France and Holland.	29 in the United Kingdom. 22 on the Continent. Countries represented being— British Isles, including the Shetlands, Hebrides, and Scilly. France, Holland, North Germany, Denmark, Norway, Sweden.
2.—NATURE OF INFORMATION GIVEN.	2.—NATURE OF INFORMATION GIVEN.
A.—*Tabular matter.*	A.—*Tabular Matter.*
For 8 A.M.:— Barometer. Dry-bulb thermometer. Wind. Weather. Sea-disturbance.	For 8 A.M.:— Barometer, and change in past 24 hours. Dry-bulb thermometer, and change in past 24 hours. Wet-bulb. Wind. Weather. Sea-disturbance.
For past 24 hours:— Extreme wind. General weather. Rainfall.	For past 24 hours:— Maximum temperature in shade. Minimum temperature in shade. Rainfall.
	For 6 P.M. on previous day (44 stations):— Barometer. Dry-bulb thermometer. Wind. Weather.
	For 2 P.M. on previous day (9 stations):— Barometer. Dry-bulb thermometer. Wet-bulb thermometer. Wind. Weather. Sea-disturbance.
B.—*Written Matter.*	B.—*Written Matter.*
Explanation of table. Remarks. Forecasts, for two days.	Explanation of table. Remarks.
C.—*Graphic Representations.*	C.—*Graphic Representations.*
Nil.	Four small charts of Western Europe, showing for 8 A.M.:— 1. The distribution of pressure, with notes as to the changes which have occurred in the different localities since the previous morning. 2. Similar information as to the air-temperature in the shade. 3. The prevalent winds, the sea-disturbance (when rough or high), and the portion of our coasts (if any) which has been warned.

1866.	1875.
	4. The weather at each station, and the regions in which a measurable quantity of rain has fallen in the past 24 hours. When the fall at any station has been heavy (*i. e.* more than 0·5 in.), the amount is entered in figures (to the nearest tenth of an inch) close to the position of the station at which it has been measured.
D.—*Corrections and Additions.* Nil.	D.—*Corrections and Additions.* At the end of each month a sheet is published containing the corrections (when obtainable) for all the errors which have been detected throughout the month, together with copies of all returns which have been received too late for insertion in their proper places.
E.—*Weekly Summary.* Nil.	E.—*Weekly Summary.* A summary of the weather over North-western Europe is published each week, giving a brief résumé of the conditions observed on each day, and a *general* summary for the whole week, calling attention to the more general changes reported.
3.—ISSUE. A *very* few copies used to be issued, viz. to certain newspapers and one or two subscribers.	3.—ISSUE. In addition to about 10 written copies (for 2nd edition of 'Times' and some other evening papers and one or two subscribers), 595 lithographed reports are printed daily. Of these about— 525 copies are issued daily. 6 do. do. weekly. 8 do. do. monthly. 16 do. do. half yearly. Of those issued *daily and weekly*, about 300 are issued to subscribers, and the remainder are sent free to Public Offices or for exhibition at seaports, or in return for observations from volunteer observers.

It should also be remarked that since the 1st of April, 1875, Daily Weather Charts have appeared in the 'Times' and other newspapers. The form of these charts and the method of producing them in time for publication were first initiated by a member of the Committee.

Since January 1, 1876, arrangements have been made by which a chart for 6 P.M. is supplied to the 'Times' at the expense of that journal.

As regards actual work effected in this Department, the Office may point to the following papers:—

N. O. 1. A Paper by Mr. Scott confirming the universal relation between the direction and force of the wind and the differences in barometrical readings, which had been already propounded by Professor Buys Ballot. This paper tended to establish the value of gradients for the purposes of weather study.

N. O. 2. A Paper by Capt. Toynbee on the curves of the Meteorological Observations taken on board the steamers running between Europe and America, showing that as on their voyages outward they meet, and on their homeward route they run with, cyclonic systems of wind which are crossing the Atlantic, the succession of the phenomena is much more rapid in the former than in the latter case. In fact, in some of the homeward runs, the barometer is found *to rise when the wind is southerly*, thus showing that the ship is outstripping the disturbance.

N. O. 3. Also by Capt. Toynbee, shows by a number of instances the value of isobaric curves for the purposes of weather study, and also draws the attention of sailors to the fact that the tack on which they are from time to time (that is, the direction in which they are sailing with regard to the wind) affects very materially the rate of the changes that are taking place in the indications of the meteorological instruments, the barometer falling less rapidly, or even rising, when they are on the starboard tack (that is, with the wind on the right), and the converse when they are on the port tack, in the Northern Hemisphere.

O. 13. Also by Capt. Toynbee, was undertaken in order to throw light on the storm in which the 'City of Boston' is supposed to have foundered. It is the most elaborate discussion of Atlantic weather which has appeared, and it shows, *inter alia*, how incomplete the materials are, and must be, for any synoptic weather-charts extending over a wide stretch of ocean. It illustrates the generation of the Atlantic winter gales over the warm-water area on the prolongation of the Gulf-stream, and proves that the centres of disturbances in some cases move to the east or north-east, at a rate exceeding 30 miles an hour—a fact which is confirmed by the records of the self-recording observatories in these islands, and by the general results of the observations made over the whole of Northern Europe.

In order to carry out the same method of investigation over a more extensive field, the Office has undertaken the examination of the weather of the Atlantic for the entire month of August 1873, when a very severe cyclonic storm swept along the American coast and did enormous damage in Nova Scotia. It is hoped that light will be thrown on the actual formation of, and the subsequent modifications in, this serious storm, so that some attempt may be made to solve the vexed problem of the precise direction of the motion of the air in cyclones in reference to the position of the centre of the disturbance. The Office has appealed to the owners of all British vessels at sea in the Atlantic during the month in question, and has met with a very satisfactory response, having received no less than 280 logs, a larger number than has ever before been available for such an inquiry.

The charge of the issue of storm-warnings &c. has necessarily been wholly confided by the Committee to the Director of the Office, who, in reply to our inquiry how far the principles by which he is guided admit of being formulated, has furnished us with the following remarks:—

"The chief of these principles, which are only announced with very great diffidence, as being liable to material modification with the growth of experience, are as follows:—

"I. *The Law known as Buys Ballot's*, which is simply a general application of the Law of Storms announced by Redfield and Reid.

"The intelligent application of this principle to wind motion, even on the most extensive scale, has been the chief point in which modern meteorology offers a contrast to prior investigations into the science.

"This law gives not only the direction of the wind, but also its force, which is measured with more or less accuracy by means of gradients. That it is not absolutely true in all cases and conditions is more than probable, although precise statements on this subject are not accessible as yet.

"As regards Direction, the indraught of wind across the isobars in front of an advancing storm is indisputable, as is the effect of land in modifying the motion of the air.

"As regards Force, it is clear that the same gradient does not accompany the same force of wind from all points. A further proof of this statement is to be found in a fact which has been elicited by the investigations into the meteorology of the sea, that for the same force of wind the gradient is less in the S.E. than in the N.E. Trade.

"II. *The mutual Relation of areas of low and of high Barometrical Pressure*, the former being to a great extent regulated as to their motion by the latter, and skirting them on their western, northern, and eastern side, at least; so that when we have an area of high pressure situated over a portion of these islands, we can form a good idea of the probable direction of motion of cyclones in our neighbourhood—*e. g.*, the existence of an anticyclone over Ireland is accompanied by the advance of cyclonic disturbances southwards over the Baltic or North Sea, causing northerly gales on the east coast of England.

"The above principle is manifestly incomplete, inasmuch as it takes no account of the rarity of any westward motion in the cyclones.

This latter circumstance, however, appears to be a local peculiarity, and it is probable that if the weather were studied over a wider area, as in the synoptic charts of Capt. Hoffmeyer, or those projected, but not yet carried out, by the United States Signal Office, light would be thrown upon it. It is certain that a motion westward does sometimes occur even over these islands, as well as in lower latitudes, as, *e. g.*, over Turkey in Asia, from Bagdad to Salonika, Nov. 3–6, 1869.

"The appearance of secondary cyclones in connexion with larger disturbances of the same nature is gradually attracting more and more attention. These systems are imperfectly developed, inasmuch as, generally speaking, they exhibit no easterly winds of much force, manifesting themselves on the southern side of their primaries, and intensifying the violence of the westerly winds which blow under such circumstances.

"It must be admitted that, not unfrequently, the arrival of one of these satellite depressions, in advance of a more serious storm, has enabled the Office to give timely warning of the latter.

"The comparative rarity of the easterly winds in our cyclonic storms is probably traceable to the constant existence of an area of deficient pressure near Iceland, which renders the formation of steep gradients for easterly winds an unusual phenomenon.

"There appear to be some indications of principles by which we can recognize whether or not a cyclonic disturbance is speedily to be succeeded by another.

"If, after the centre of a depression has passed over us, the shift of wind and fall of temperature causes a great clearness of the air, intense radiation occurs at night, the thermometer on the grass falling 10° to 14° below that in the shade 4 feet above the ground. Under such circumstances it has been noticed that the advent of a new depression is imminent. When, however, the series of successive depressions has ceased for a while, the weather clears much less rapidly, and radiation is not nearly so marked.

"On the whole thus much may be affirmed, that it is to the general conditions of atmospherical pressure *over as large an area as possible* that we are to look for an insight into the probable changes which are likely to ensue. To this subject I shall shortly recur.

"III. *Temperature.*—As regards the relation of this element to atmospherical disturbance, there are no definite principles which can be said to be generally admitted as true. This may be gathered from the almost total silence on this subject on the part of those who replied to the circular of the Leipzig Storm-Warning Committee in 1872.

"Thus much may, however, be said:—

"A great contrast of temperature over a limited area, or, so to speak, a great thermometric gradient, being an indication of serious atmospherical disturbance, is a precursor or concomitant of a storm. This fact has been clearly pointed out by Dove; but more recent evidence on the same head is to be found in the circumstance that for five days, January 26–30, 1870, the mean of the temperatures at 8 A.M. at London and Valencia differed 16°, being 28° and 44° respectively, a heavy southerly gale blowing all the time over Ireland. A more recent instance, in which a remarkable contrast of temperature immediately preceded a very serious storm, was on the 13th of November, 1875, when the reading at Scilly was 57°, and at Wick 21°. These figures give the very large difference of 36°. The gale of Sunday, November 14th, with its accompanying high tide, will be fresh in the memory of all.

"Another mode of utilizing temperature in the forecasting of storms is to be found in the long-established fact that an abnormally high temperature, close stuffy weather, frequently precedes a storm. This principle has not been reduced to numerical measure as yet.

"IV. *Vapour-Tension and Rainfall.*—Very much weight is attached by several meteorologists to the indications obtainable from these elements, as Mohn and Loomis consider that their disturbance and intensity determine the direction and velocity of motion of cyclones, and that even the very existence of a cyclonic disturbance depends on the presence of aqueous vapour in abundance.

"For the area of our storm-warning system this indication is necessarily of minor value, inasmuch as our district is so intersected by water that no portion of it will show such contrasts in regard of vapour-tension as subsist in continental stations.

"V. *Sea-Disturbance.*—This is at times a most valuable help towards gaining a knowledge of coming storms; but it is very untrustworthy. The sea-disturbance, being caused by the wind, is propagated in the direction in which that wind is *blowing*, not in that in which it is *advancing*. Thus a very heavy sea may roll in on our coasts without any gale reaching them; and conversely heavy gales, even westerly gales, like that of November 22, 1872, may come on without any premonition in the way of a ground-swell.

"The distance to which waves may be propagated is indicated by what has already been mentioned as probable, that the 'rollers' of Ascension and St. Helena may be due to N.W. gales in the North Atlantic.

"VI. *Local Signs.*—These are really among the most important indications of coming change; but practically they can scarcely be utilized by us. They cannot be reduced to rule, and they depend almost entirely on personal experience. It is impossible in a telegram to convey the entire line of reasoning which leads one, in the absence of instruments, to know that a storm is impending. The character, elevation, and motion of clouds, the colour of the sky, the clearness or the contrary of the air, the appearance of the aurora, and numerous other signs are well known to every one who studies weather; and from these helps the cabinet meteorologist is entirely debarred. He is like a physician dealing with a case by correspondence, without the chance of a personal interview with his patient; for what can a resident in an inland town like London, on any given day, know of the look of the weather on the sea-coast on the same day.

"If, in conclusion, I were asked how our weather service could be most directly improved, on the supposition that larger means were available for its prosecution, I should say,—

"A. The supply of cheap self-recording instruments to our principal stations, so that the reporters should be able to furnish intelligence as to the changes which have taken place immediately previous to the epoch for which the report is framed.

"The erection at a number of well-exposed outlying stations of the automatic signalling-anemometers described in the Report of the British Association for 1874, p. 37, in order to warn the nearest telegraphic stations of the fact that the wind has reached a given velocity, say 30 miles an hour. Want of funds has hitherto prevented the carrying out of this plan.

"B. Additional stations at well-selected points on our west coast, as at Mullaghmore, on Donegal Bay, and at high levels, as at Settle, in Yorkshire.

"The former especially to give more accurate indications of wind, which from our present stations is often necessarily incorrect, owing to the precipitous character of our western coasts, which affects the direction and force of the wind. The latter to furnish means for a study of the differences of atmospherical conditions in a vertical direction, which has yielded very valuable results whenever it has been prosecuted.

"C. Additional reports daily. This is a most pressing want; it has been partially met by the enterprise of the public press, the 'Times' having begun (Jan. 1876) to bear the expense of an evening message from some stations.

"D. Improved accuracy in transmission of the reports. This is, I fear, hopeless!

"E. Extension of the area covered by our reports. This raises the question of international exchanges; and in this particular it must be remembered that stations are not of equal value, for a report from an outlying post, as Valencia or Sumburgh Head, is worth to the continental meteorologists many times more than a report from a continental station is to us.

"The extension of our system westwards, were it possible, would be of incalculable value; but America and even Newfoundland are too distant for us to reason with any degree of certainty on what the changes taking place there may portend to us.

"Reports from the Azores, if supported by others from Spain and Portugal, would be of value; but they would require confirmation. At least two simultaneous reports from independent stations in that group of islands would be required, in order to afford means for checking doubtful statements or errors in telegraphy.

"F. An increase of the staff of the Office.

"To summarize. More information from existing stations, a large extension of our area of observation, and a reinforcement of the staff for weather study, are the chief requirements of our telegraphic system at present."

In the matter of the "Recommendations on the subject of Weather Telegraphy, Daily Forecasts, and Storm-Warning, and upon observations of Weather within or affecting the British Isles," made by the Committee of Inquiry (1866), it may be said that the progress of this department of meteorology since 1866 has been so considerable that the importance of several of the Recommendations has been materially modified by recent experience. The Office has carried out the recommendations in principle as regards the development of the observing system, the issue of storm-warnings, and the discontinuance of weather forecasts, and as to the checking of the warnings. It has not, however, for reasons which will be stated hereafter, published a series of maxims, nor has it been found possible, with the present staff, to analyze strictly the principles on which the issue of warnings, &c. has been carried out from day to day.

The staff has been quite insufficient to cope with the serious discussion of the weather charts which are daily accumulating.

The Office has cooperated readily with the United States Signal Office in its project for synchronous observations over the whole globe.

III. LAND METEOROLOGY OF THE BRITISH ISLANDS.

This branch of the Office has been carried out in accordance with the plan sketched out in the letter from the President and Council of the Royal Society to the Board of Trade of June 15, 1865, approved by the Committee of Inquiry (1866), and sanctioned generally by the Treasury in a letter to the Board of Trade, dated November 30, 1866. The number of stations originally proposed was six, with possibly two additional points of observation, situated in the south-west and in the north-west of Ireland respectively. The six stations specified were accepted and have been in continual operation until now. The Treasury did not sanction the insertion on the estimates of the full sum proposed by the Meteorological Committee for the year 1867–68; and accordingly the Committee at first determined to defer the establishment of the station at Aberdeen, in consideration of the greater importance of records from Valencia. At the request of the authorities at Aberdeen, conveyed through the Duke of Richmond, Chancellor of that University, the Committee resolved to reconsider their proposal; and ultimately Aberdeen was included in the list of places fitted out with self-recording instruments.

The choice of these stations was guided by the fact of the existence in each locality, except Valencia, of some scientific body to whom the instruments could be entrusted. This involved the necessity of placing the instruments in the best available positions on the premises of the respective institutions, the funds available being totally inadequate for the erection of special structures for the reception of the instruments or the maintenance of special observing establishments. Hence have arisen the defects in arrangements as concerns temperature in regard of elevation above the ground at Falmouth and Aberdeen, and to a less degree at Valencia, and as to proximity to buildings in all the observatories. In respect of the four other observatories, not above named, there is no doubt the thermometrical indications do afford as thoroughly satisfactory a record of temperature as is required—this point having been proved by direct experiments by Dr. Stewart for Kew, and by the Rev. Dr. Robinson for Armagh.

Absolute uniformity in conditions of exposure is totally unattainable, as was fully recognized at the Vienna Meteorological Congress in 1873.

The observatories were set in action in 1868, and with the year 1869 the publication of the 'Quarterly Weather Report' was commenced. This was projected in order to overcome the difficulty, universally recognized, of the absence of uniformity in epochs of observation in the different countries. A reproduction of the automatic curves was considered to be of paramount importance in order that the records at observatories should be independent of any choice of hours for observation or of any scales, and the value of such a reproduction was strongly urged by the Committee of Inquiry (1866).

The execution of the plates was rendered possible by the invention of certain special instruments and processes, for which the Office is indebted to Mr. F. Galton and Mr. De La Rue, and which are in constant use, as explained in the several Annual Reports of the Office.

The curves were at first reproduced by the lithographic process, but of late years that of copper-plate printing has been introduced.

The degree of accuracy aimed at is 0·02 in. for the barometer, and 0°·5 for the thermometer; and the plates furnish a continous record of—

Pressure.
Temperature (Dry and Wet Bulb).

Vapour-Tension.
Wind (Direction and Hourly Velocity).
Rain (Hourly Amount).

It may be asserted, without fear of contradiction, that no record of a completeness and accuracy at all approaching that attained by the plates in question has yet been attempted in any other country, and that moreover the Meteorological Office is the only Meteorological establishment which itself publishes the materials for testing the accuracy of its published numerical values.

In the matter of accuracy many important advances have been made since 1867, owing to the growth of experience, and the methods of treatment of the records have much improved.

The text of the 'Quarterly Weather Report' has been a consecutive journal of the weather, and the tables have given the five-day means of the barometer and the dry and wet thermometer, from hourly measurements of the curves, together with monthly means of the same elements, and of vapour-tension and deduced dry-air pressure, as well as extreme readings of the barometer and dry thermometer.

A request having been made for the publication of the actual hourly readings of the measurements of the curves, this has been complied with. These volumes have been issued since January 1874, and distributed to the principal libraries at home and abroad.

The preparation of the plates and tables above mentioned occupies nearly the entire time of the available staff of the Office; so that no present prospect exists of a systematic discussion of the returns, so as to calculate the periodical variations of the different elements. This for the seven observatories will be a heavy task; and it is for consideration whether some special steps should not be taken for effecting it, as the first five-yearly period over which the observations extended closed with the past year, and it was held by the Vienna Congress that such calculations should be effected for "lustra" (periods of five years) ending with years which, according to our present calendar, are multiples of five.

The 'Quarterly Weather Report' has contained in addition various appendices, which are as follows:—

1869. Notes on easterly gales.
1870. Mean barometrical pressure at telegraphic reporting stations.
Rainfall at telegraphic reporting stations.
A translation of Bessel's Paper on the Determination of the Law of a Periodical Phenomenon.
1871. A discussion of the anemometrical results for Sandwick Manse, Orkney, 1863–68.
Mean monthly rainfall at certain stations in the United Kingdom.
Constants for Bessel's Formula for the Observatories for 1869–70.

1872. Discussion of the anemometrical results at Bermuda, 1859–63.

1873. Rainfall of the London district for 60 years, 1816–1872, by G. Dines, F.M.S.

Results of observations taken at certain stations of the Second Order for the year 1873.

The Appendix last mentioned leads to an important subject calling for remark—the study of the climatal conditions of these islands by means of returns from stations auxiliary to the self-recording observatories.

Such stations have been gradually organized; and in January 1873 the Committee were able to inform the Registrar-General, in reply to an inquiry made by him, that if the Office were called upon to furnish materials to him for his statistical returns, it was in a position to do so.

Of late the list of stations in connexion with the Office has received an important reinforcement by the conclusion of an arrangement by which the Meteorological Society (of London) supplies returns from some of its stations, in return for a small annual grant to defray the expense of copying.

That Society has recently organized a system of stations with much care, which exhibit a satisfactory agreement as to the character of the instruments and the conditions under which all the observations are taken.

This cooperation of the Society, and of a considerable number of private observers throughout the country who have volunteered to supply their schedules of observation gratis, renders it possible for the Office to take its part in the general international scheme of publication of returns from eye-observations proposed by the Permanent Committee of the Vienna Congress, in order to facilitate climatological inquiries.

The publication of these returns, demanded for 15 stations in the United Kingdom, has been commenced for England and Ireland. As for Scotland, it is hoped that the Scottish Meteorological Society will supply their quota of materials for this international object.

The Committee have felt it their duty to afford every facility to their Director to attend, as their representative, the meetings of the various Meteorological Congresses which have been held of late years, and, moreover, have entertained the members of the Conference on Maritime Meteorology, which was held at their Office in August 1874.

The Office is therefore at present fulfilling all that is called for from this country for international purposes, as defined by the Permanent Committee of the Vienna Congress; and there can be no doubt that the information now coming in is, as regards accuracy, fully equal, if not superior, to any published from a similar system of stations in any country.

Further may be mentioned the fact of the recent publication by the Office, at the request of the Government, of a volume entitled "Instructions in the Use of Meteorological Instruments," which has been compiled with the assistance of several meteorologists unconnected with the Office.

The Scottish Society have sought to obtain a grant in aid of their general objects from the Parliamentary vote; but the Committee have considered that, as they are only agents for directing the application of the fund at their disposal, they have no authority to make grants to be dealt with at the discretion of other bodies, and that their action is restricted by the conditions that the objects to which it is directed shall be among those for which the grant is made, and that the expenditure shall take place in a manner that admits of their exercising a control over its objects and results.

Before leaving this branch of the subject, the Committee would remark that their operations would have been seriously crippled in the year 1871, when the British Association withdrew its annual subsidy to Kew Observatory, the central observatory of their system, had not Mr. Gassiot, one of their own body, come forward and most munificently placed in the hands of the Royal Society a sum of £10,000 for the endowment of the establishment, thereby affording ample funds for the continuance of the observatory in full activity.

In conclusion the Committee would make a few general remarks on the principles that have guided them in organizing the Meteorological Office and controlling its operations.

They have considered it to be their duty to give general effect to the recommendations of the Committee of 1866, and to establish and carry on for a considerable length of time, with the least possible amount of change, a well-arranged and uniform system of observation and of publication, being satisfied that continuity of method is one of the most essential elements of success in dealing with complicated physical phenomena.

The Committee on their first appointment laid down with much deliberation the course to be pursued by the Office, and gave considerable attention to the removal of the numerous difficulties which necessarily occurred in the establishment of so much that was novel, especially in connexion with the self-recording instruments.

Seeing that the Committee of 1866 had recommended a renewed inquiry into the proceedings of the Office after three years' trial, and feeling that under any circumstances its constitution was only provisional, the Committee have aimed at leaving the principal officers employed in the duties of the department as little fettered as possible as to the precise manner in which details were conducted, looking rather to securing satisfactory results of the work, and to exercising that strict financial control over the application of the funds placed at their command which their duty to the Royal Society and the Government required of them.

They have also felt that, in the existing condition of meteorological knowledge, it would have been not only presumptuous on their part, but positively mischievous to have attempted to assume a position of authority in enunciating new doctrines of their own or in criticising the opinions of others, and that their power of producing useful results would have been seriously impaired if they had in any way departed from the purely neutral attitude of accumulating a faithful record of facts destined to furnish materials for scientific discussion.

Although there exists a large quantity both of published and unpublished data in the possession of the Office, which places their staff in an exceptional position for conducting elaborate investigations into the conditions of the weather, nevertheless the Committee have found it impossible to provide for the adequate carrying on of such investigations by means of their own staff, the time of their chief executive officers being so much occupied by the heavy current business of the Office as to leave them no leisure for the purpose; nor have the Committee been able to assign out of the funds at their disposal enough to secure additional assistance of a proper scientific character. If they had diverted any of these funds to purely scientific discussions it would have crippled other parts of their work, which appeared to them, under the existing conditions and for the time being, to be still more important and to be, in a measure, obligatory on them.

It will readily be understood that the Committee holding such views makes no claim to having given an independent impetus to the progress of any special branch of meteorological science, though they feel satisfied that their operations have in an important manner facilitated the natural development of accurate meteorological conceptions. All conversant with the facts will agree that a very great advance has been made in this respect since the Committee was formed. The Committee will not attempt to distinguish all the various causes that have conduced to this advance; but among them are certainly to be recognized the organization of the system of continuously self-recording observatories and the publication in the 'Quarterly Weather Reports,' with a remarkable degree of accuracy, of a graphical reproduction of the records thus obtained; the constantly increasing attention paid by the officers of the Meteorological Office to the accurate and prompt preparation and distribution of the lithographed Daily Weather Charts, their intelligent study of the facts recorded under their direction, and their cordial cooperation with other bodies interested in similar objects, whether in this country or abroad. The experience gained in the preparation of the Daily Morning Weather Charts has enabled the Office to prepare smaller charts, which are supplied for publication in several daily papers in London and the provinces. This indication that such information is appreciated by the public is further corroborated by the fact that similar Charts containing information for the evening have been asked for, and are now furnished by the Office to the 'Times.'

The Committee being aware that the Government has entrusted to another body the duty of inquiring how the functions they have performed may best be discharged in the future, they will only permit their remarks to extend beyond a review of the past in three particulars.

First. They look forward with great hope to the effect of increased international cooperation on a large scale, towards which important steps have already been taken at recent Meteorological Congresses. The detached labours of numerous meteorological institutions will thereby be presented in a strictly comparable form, and may readily be combined in synoptic charts or in any other manner into a single whole. They think it is impossible to overstate the importance of measures tending to such a result.

Secondly. They consider it to be a point of much importance that the meteorological societies and independent observers of this country should be more generally induced to work in unison with an Office maintained by grants from Parliament, so far as their several efforts are directed to the same field of inquiry. Administrative difficulties have hitherto prevented the accomplishment of as much in this direction as could be desired; but the Committee fully recognize that it would be advisable to utilize more completely than has yet been done the energy of independent meteorological societies or individuals, and they believe that this admits of being effected on conditions that would be suitable and acceptable to them.

Lastly. They feel it necessary to say that for the further advancement of Meteorology greater attention to its more strictly scientific aspect will in the future be essential. Merely empirical rules, however sound be their foundation, can never become really trustworthy guides of action until the principles that underlie them are established, and the circumstances are appreciated under which deviations from the ordinary course of events arise. It can hardly be disputed that in the course of the past nine years, since the appointment of the Committee, the general progress of the science of Meteorology in this country and abroad has been such that the application to it of exact principles seems to have become not only possible but requisite; without them the full practical advantage of existing means of observation will not be secured, and it is only by aid of scientific discussion of the facts that these principles are to be ascertained.

They would suggest, as a probable mode of attaining the object they have in view, the application of a portion of any future grant to the preparation of reports, or the carrying out of researches on special subjects connected with meteorological science by qualified persons to be selected from without and employed independently of the ordinary staff of officers engaged on other duties.

The Committee are only too well aware of the difficulties that are likely to attend the progress of Meteorology as an exact science; but difficulties apparently as great have been overcome in other directions, and perseverance and time will doubtless remove those now in question.

IV. "On the Structure, Physiology, and Development of *Antedon* (*Comatula,* Lamk.) *rosaceus.*" By WILLIAM B. CARPENTER, M.D., F.R.S. Received December 16, 1875.

[PLATES 8, 9.]

When, in 1865, I communicated to the Royal Society the First Part of a Monograph on the Anatomy, Physiology, and Development (excluding the earliest stages previously described by Prof. Wyville Thomson) of an animal which might be regarded—except in certain comparatively unimportant particulars—as a type-form of the whole CRINOIDAL series, I had so nearly concluded my investigation of the subject of it, that I fully contemplated the presentation of the Second and concluding part in the course of a year or two. Uncertain health, however, interfered with its completion in the first instance; and my spare time has since then been so far taken up by the various inquiries that have arisen out of the Deep-Sea researches which I prosecuted in the vacations of 1868 and three following years, that I have found myself quite unable to resume the study of *Antedon.* Thus it comes to pass that, though I have now had by me for a period of ten years the results of my previous labours, as presented in several hundred preparations, with a series of most admirable drawings executed by Messrs. George West and A. Hollick, illustrating almost every point of primary importance not only in its structure, but also in the history of its development from nearly the earliest Pentacrinoid stage, all this material has remained unpublished; for I have felt that the completion of my Monograph in a manner worthy of its subject required that certain obscurities should be dissipated and certain gaps filled up; and it now, also, becomes desirable that the Histology of this type should be more fully elucidated by the aid of modern appliances, and that the earliest phases of its Development should be thoroughly reinvestigated. I especially desire to ascertain whether the free-swimming larva (or pseudembryo) has a *Gastrœa* stage, and to follow out the derivation of the gastric and perivisceral cavities of the Pentacrinoid, and of its original tentacular system, from the structures of the pseudembryo—points on which Prof. Wyville Thomson's Memoir, admirable as it is, does not enlighten us. This stage of the history has been subsequently studied by a most able observer, Herr Metschnikoff*; and the conclusions he has arrived at in regard to the origin of the tentacular system I find to be essentially accordant with those which I had drawn from my own researches on a later stage.

In the autumn of the year 1868 I had the pleasure of a visit from Dr. Semper, who had then newly returned from a long residence in the Philippine Islands, where he had not only made a large collection of different species of *Antedon* (including many new ones of singular con-

* Bulletins de l'Acad. Impér. de St. Pétersb. 1870, pp. 508, 509.

formation), but had also investigated their structure to an extent sufficient to enable him to recognize the erroneousness of many of the statements put forth by Prof. J. Müller in his celebrated Memoir of 1841, 'Ueber den Bau des *Pentacrinus Caput Medusæ*,' which has been the principal authority as to the structure of the Crinoidea for all subsequent writers of zoological text-books. I then placed before Dr. Semper not only the already published First part of my Memoir, but also the materials I had collected for the Second; and finding that my main conclusions agreed completely with those at which he had arrived, he most kindly offered to hold back the publication of his own views until I should have given mine to the world. Having been subsequently appointed to the Chair of Zoology in the University of Wurzburg, Prof. Semper has of course taught to his students what both he and I regarded as the truth of many things erroneously viewed by J. Müller; and another investigator, M. Edmund Perrier*, having in the meantime entered the field, and reproduced some of Müller's errors, Prof. Semper has thought it right to give a wider publicity to his convictions on the subject, which my own protracted delay fully justified him in doing. "In the year 1868," he says, "I was intending to publish a short memoir on that which I had found, when, becoming acquainted in London with Dr. Carpenter, I was delighted to learn that that able observer had obtained exactly the same results on European as I on Philippine *Comatulæ*. In the expectation that the English investigator would soon publish his already prepared work on the Crinoidea, I deferred till now the communication of the results of my examination: but since, after five years waiting, there is imminent risk that from my lectures the results of Carpenter's and my own toilsome investigations may somehow find their way into publicity, I hold that the moment has arrived to break the silence I have hitherto kept"†. For the same reason I think it desirable to place on record without further delay the general results of my own investigations, with such illustrations as may render my descriptions intelligible—though I have reason to hope that the time may not be far distant when I may be able to present to the Royal Society the Second Part of my Memoir, giving with the First such a detailed account of the Structure and Life-history of this type as may serve as a basis for the description of the Pedunculate Crinoids known as living types. Of these I have already examined two of the West-Indian species of *Pentacrinus*, with the *P. Wyville-Thomsoni* (of which several specimens were obtained in the second 'Porcupine' Expedition off the coast of Portugal); and I have further information to give on the *Rhizocrinus Lofotensis* (Sars), the recent type of the Apiocrinida. These, with the numerous other Crinoids collected during the 'Challenger' Expedition, will doubtless furnish ample materials for such an elucidation of the Structure and Life-history of this most interesting group as may afford a secure basis for the scientific study of its great Palæontological series.

---

* Archives de Zoologie Expérimentale, tom. ii. 1873, pp. 29–86.—This observer has confined himself to the study of the arms, examining their terminations as transparent objects. In this manner he has added much to our knowledge of their Histology; but, through not having examined *transverse sections* of the arms and pinnules, he has not only failed to recognize the true tentacular canal, but has been led to affirm that there is only one canal-system in the brachial apparatus.

† Ann. & Mag. Nat. Hist. Sept. 1875, p. 202.

ANATOMY.

Calyx and its Contents.

Calyx.—The shallow basin (Phil. Trans. 1866, plate xxxii. fig. 2) which holds the central portion of the visceral apparatus is formed not only by the first, second, and third Radials, but also by the first and second pairs of Brachials, together with the basal segments of the pinnules borne by the second—these portions of the calcareous skeleton being so connected laterally by intervening perisome as to complete the wall of the concavity. This concavity is lined by a smooth membrane, which may be conveniently and, I think, correctly termed *peritoneum*, as it forms the immediate boundary of the perivisceral cavity or *cælom*. The calyx is shut in above by the perisome of the oral disk, which is lined by a continuation of the peritoneum; and this is also reflected over the "visceral mass" which occupies the cavity thus enclosed. This "visceral mass" is a compact lenticular body, which includes the whole digestive and sanguigenous apparatus, with the central portion of the circulatory and respiratory systems and the prolongation of the axial cord of the stem, from which is given off the generative *rachis* that passes into each arm; but it does not include either what I regard as the nervous centre or the generative organs (testes or ovaries)—the former being contained in the cavity of the centro-dorsal basin which underlies the calyx, while the latter, as has long been known, are distributed through certain pinnules of the arms.

Oral Disk.—The membranous perisome which forms the oral disk is continuous with that which is prolonged over the oral surface of the arms and pinnules, and which also dips down between the basal segments of the arms to complete the cavity of the calyx. Towards the mouth (Phil. Trans. 1866, plate xxxii. fig. 3), which is situated in its centre, five radial furrows converge, each of them formed by the union of two converging brachial furrows. The distance from the mouth at which thi union takes place is by no means constant; and I attach little value as a specific character to variations in the distribution of these furrows. The floor of each consists of what appears to be a layer of columnar epithelium, which I believe to be ciliated. Its sides are formed by elevated ridges of the perisome, each of which is scolloped at its edges so as to form a row of minute valvules (the "crescentic leaves" of

Wyville Thomson), from within every one of which there rises a pair of non-extensile tubular tentacles. Each pair of tentacles springs from a base common to it with the leaflet; and this base communicates by a single oval orifice with the *tentacular canal*, which lies immediately beneath the epithelial floor of the furrow. (This is quite distinct from the "tentacular canal" of previous authors, which lies below it and has no connexion whatever with the tentacles, and which I term the *subtentacular canal*.) The convergence of the five radial furrows towards the mouth gives it when viewed from above somewhat the form of a five-rayed star, the adjacent rays being separated by rounded projecting lobes of perisome (Plate 8. fig. 2, *m*, *m*), beneath which (as shown at *a*, figs. 2, 3) is situated the true mouth surrounded by a thickened annular lip. Within each of the five lobes of perisome there arise from the annular lip, by separate bases, a series of from eight to ten thick-walled tentacles, each of which has its own orifice of communication with the interior of the oral ring.

The true *tentacular canals* are the representatives of the "radial vessels" described by Prof. Wyville Thomson, in his account of the Pentacrinoid larva, as extensions of the oral-ring canal, which, as will hereafter appear (p. 227), is a derivative of the perivisceral cavity, marked off from it by threads of connective tissue, as shown at *rc*, figs. 10, 11. In the adult *Antedon*, however, the thickened annular lip which surrounds the mouth does not contain any distinct ring-canal, its original cavity having been almost entirely filled up by threads and bands of connective tissue, and by a set of cæcal tubuli, as to the precise relations of which I am at present in doubt. But the true tentacular canals still pass towards it, and seem to lose themselves in what may be called its "interspace system," this being continuous with that which has come almost entirely to occupy (as shown in fig. 3, *k*) the portion of the perivisceral cavity that originally lay open within the intestinal coil.

The *subtentacular canals*, on the other hand, radiate continuously from the neighbourhood of the mouth to the bases of the arms, each of the five radial trunks divaricating into two; but they do not give off any branches or extensions whatever until they reach the arms, where alternating lateral extensions pass into the pinnules. On approaching the mouth, where the oral perisome becomes continuous with the lining of the œsophagus, these canals dip downwards into the "visceral mass," as was long since described by Heusinger[*], though he did not trace their further course in its interior. I shall presently show that they there all become continuous (as at *l*, fig. 2) with the single "axial canal" (*g*), which passes downwards towards the centre of the dorsal surface of the visceral mass, and, through that canal, with the deeper or dorsal portion of the perivisceral cavity. And the history of the development of the subtentacular canals (Plate 9. fig. 12, *stc*) plainly shows that they too are derivatives from the upper or oral portion of the same cavity, which the progressive increase

[*] Zeitschrift für organ. Physik, Bd. iii. (1829), p. 366.

of the visceral mass, and the formation of membranous adhesions (as at *m*, fig. 12) between the apposed surfaces of its peritoneal covering and of the peritoneal lining of the calyx, separate into an upper and a lower portion, whose communication with each other is maintained by the axial canal.

The oral perisome is perforated in the spaces between the radial furrows (especially near the angles formed by their junction in the mouth) by numerous minute pores surrounded by ciliated epithelium, whose cilia I have seen in extremely active movement, apparently inwards. These are the orifices of funnel-shaped canals, which first pass vertically through the perisome, and then contract and take an oblique direction, opening (I believe) into a system of sinuses, which are left by the incomplete adhesion of the peritoneum covering the upper surface of the visceral mass to that which lines the under surface of the oral perisome. If this be the case, they obviously establish a direct connexion between this limited portion of the perivisceral cavity and the medium inhabited by the animal; and the water thus introduced probably serves a respiratory purpose*.

Perivisceral Cavity.—The adhesion of the under surface of the oral perisome to the upper surface of the visceral mass is so close that they can only be detached by tearing, after both have been hardened in spirit. The peritoneal covering of the lower or dorsal surface of the visceral mass, on the other hand, is but slightly adherent to the opposite peritoneal surface lining the deeper part of the concavity of the calyx, although usually in close contact with it; and thus, when the periphery of the oral disk has been cut through, the visceral mass adherent to its lower surface may be lifted entire out of the calyx, without rupture of any thing but a pedicle (*h*, figs. 2, 3) which passes up as a continuation of the original Crinoidal axis, through the "rosette" (Part I. § 35) formed by the metamorphosis of the original Basals. Hence it often happens that, through the tearing of their oral perisome, which is very soft in the living state, specimens of *Antedon* come up in the dredge completely eviscerated; and I have strong evidence that even this loss may be repaired (as the like evisceration is said to be in *Holothurida*) by the production of a new visceral mass from the "axial prolongation."

Although the visceral mass so nearly fills the cavity of the calyx that scarcely any space exists between their apposed peritoneal surfaces, yet the existence of a true peritoneal cavity becomes obvious at the bases of the arms; for it is there prolonged, in each arm, into an extension (*cc*, fig. 7) which forms a canal that underlies the subtentacular canal (*stc*) proceeding into it from the oral disk; and, like that canal, it not only passes along the whole length of each arm, but also gives off lateral extensions (*d d*) that proceed to the extremities of the pinnules. This canal, as being a direct extension of the body-cavity or *cœlom*, I term the *cœliac* canal.

---

* These canals have been noticed by Grimm (Bulletins de l'Acad. Impér. de St. Pétersb. 1872, pp. 3–8); but he has not been able to trace their internal connexions. By Perrier (*loc. cit.*) they are described as cæca.

Visceral Mass.—The "visceral mass" primarily consists of an alimentary canal (not distinctly differentiated into œsophagus, stomach, and intestine), which makes about one fourth more than a single round turn upon itself (*bcd*, fig. 1). From the central mouth this canal at first passes obliquely downwards (*b*, figs. 2, 3), then changes its direction to the horizontal, and, after making somewhat more than a complete circuit, turns upwards again (at *d*, fig. 1) towards the oral disk, to terminate in a vent which projects upwards from its surface between two of the radial furrows, the terminal portion of the alimentary canal being separated from the cavity of the vent by a valvular projection of its lining membrane.

The membranous wall of the alimentary canal may be called its mucous lining. It is somewhat rugose in the first or oblique part of the canal (*b*, fig. 2); whilst in the horizontal coil it is nearly smooth on the peripheral side, but deeply plicated on the central side (fig. 1), there forming, with its epithelial (?) covering, a sort of glandular mass*, the projection of which into the canal considerably narrows it, as shown at *e*, fig. 2. The whole smooth inner surface of the mucous lining (*b*, *c*, fig. 1) is covered with a layer of a yellow substance, which is so soft in the living state that it is difficult to separate it for microscopic examination, but which, when hardened in spirit, readily detaches itself from the subjacent membrane in large flakes, which are so opaque as not to be readily examined minutely. The appearances presented by thin sections of this layer, however, dispose me to think that it may be regarded as a columnar epithelium imperfectly differentiated into cells; and it can scarcely be doubted that the portion of it forming the large gland-like projection just alluded to has an hepatic function. The projecting edges of its plicated surface are fringed with long cilia, whose function is obviously to produce an indraught into the mouth, and to propel the ingested matter along the canal.

The exterior of the mucous wall of the alimentary canal is not in immediate contact with its peritoneal covering; but a continuous space is left between them, which is everywhere traversed by lamellæ of connective tissue passing between the apposed surfaces. This, which I shall call the *intramural* space, is much more distinct in some varieties of *Antedon rosaceus* than it is in others—the Lough Strangford variety presenting it in the most strongly marked degree, while in the Plymouth specimens the two membranes approximate each other much more closely, the Clyde variety, which is the one I have most studied, holding an intermediate position in this particular.—The like difference presents itself in the amount and openness of the "interspace system" to be presently noticed.

---

* A section of this portion very closely resembles the *arbor vitæ* of the cerebellum, the grey substance being represented by the yellow epithelial layer, and the white by the plications of the mucous membrane and the sinuses which they enfold.

The double wall of the alimentary canal is strengthened by the interposition of discoidal calcareous plates; and it is the complex plication of the wall on the central side of the canal, and the consequent piling-up of numerous layers of these disks, which forms the vertical *columella*, erroneously likened by some writers to the sand-canal of Starfish. Besides these disks, there are occasionally to be found minute calcareous spines projecting from the inner surface into the cavity of the alimentary canal, as if they were pegs whereon to hang the epithelial layer.

The interior of this *columella* is traversed by a canal (*g*, figs. 1, 2), which constitutes a most curious feature in the structure of the visceral mass. When the visceral mass has been turned out of the calyx, its lower surface shows a minute pore nearly in its centre; which pore, partly occupied (and often concealed) by the pedicle already spoken of (*h*, figs. 2, 3), is the orifice of communication between the deeper portion of the perivisceral cavity and the "axial canal," which is simply a "survival" of what was originally the part of that cavity segregated from the rest by the winding of the horizontal extension of the alimentary canal round its stomach. The axial canal at first passes upwards almost along the central axis (figs. 2, 3) of the lenticular visceral mass; but as soon as it meets the obliquely descending commencement of the alimentary canal, it too becomes somewhat oblique, lying in close contiguity to the exterior of the digestive cavity. Before, however, it reaches the oral surface of the visceral mass, it subdivides irregularly into five branches, which embrace the œsophageal part of the alimentary canal, and there become continuous, as I have already mentioned, with the five radial canals that lie beneath the tentacular canals of the oral disk, one of which is seen in transverse section at *l*, fig. 1, and others at *i*, *k*. Thus, through the subdivision of the five radial canals of the disk into the ten brachial canals, each of which gives off lateral branches that proceed to the extremities of the pinnules, there is a continuous canal-communication from the axial canal, and hence from the deeper part of the perivisceral cavity through the entire apparatus of arms and pinnules. But the axial canal is also in relation with the wall of the alimentary canal; for between the plications of the inner or central side of the latter there is a very extensive system of irregular passages or interspaces (*k*, fig. 3), which open into the axial canal; and it can scarcely be doubted that these serve, like the mesenteric vessels of higher animals, to receive the nutritive fluid which has transuded through the wall of the alimentary canal, first through the mucous lining into the intramural space, and thence through its peritoneal covering into the perivisceral cavity and its derivations.

Cavity of the Centro-dorsal Basin.—In my previous Memoir I fully described the "centro-dorsal" basin-shaped plate whereon rests the circlet of first Radials, whilst from its free or dorsal surface extend the clusters of prehensile cirrhi that functionally replace the Crinoidal stem, though homologically they correspond to the nodal verticils of cirrhi borne by the stem of *Pentacrinus*, which themselves take on the prehensile function when, as not unfrequently happens, this stem breaks off just beneath the nodal segment. And I further showed that in the early Pentacrinoid stage of *Antedon* the centro-dorsal segment is not distinguished from the ordinary segments of the stem, and that its enlargement commences with the development of the cirrhi, of which there is at first only a single whorl, but of which two complete verticils at least are present when the young *Antedon* drops off the stem. Again, I showed that in the early Pentacrinoid stage the Basals, not the first radials, rest upon the centro-dorsal segment; and I pointed out how, with the metamorphosis of the circlet of basals into the "rosette," and the progressive enlargement of the centro-dorsal plate, the first radials come to form the central basis of the calyx, resting on the infolded lip of the centro-dorsal. I refer to this now, because it helps greatly in the comprehension of the real import of the curious organ contained within the centro-dorsal basin of the adult *Antedon*; for there is no such basin in the Pedunculate Crinoids, whose calyx rests upon the uppermost segment of the stem, which segment, instead of being the largest, is the smallest, being the latest formed, while the basis of the calyx is formed by the thickened and solidified Basals. Hence it seems clear that the extraordinary development of the highest segment of the stem into the centro-dorsal basin, which is characteristic of the mature *Antedon*, is connected with the multiplication of the prehensile cirrhi which extend themselves from its dorsal surface. The number of these cirrhi, as I formerly showed, is very variable; and I gave reasons for the belief that there is a successional production and exuviation of these appendages, at any rate during the period of growth.

When, by the action of dilute acid, the calcareous network of the centro-dorsal plate has been dissolved, so as to give access, by dissecting away its soft animal basis, to the contents of the cavity, we find it to be almost entirely occupied (as seen at *g*, fig. 3) by a curious hollow, slightly pentangular organ (figs. 4, 5), which was described by Müller as a single-chambered heart. From the angles of the lower or dorsal part of this organ there proceed numerous slender cords (*l*, fig. 2), which pass through the calcareous wall of the centro-dorsal basin into the cirrhi; whilst from the upper part of its peripheral wall are given off five large radiating cords (fig. 3, *l*, *m*), which pass upwards and outwards through the canals formed by the inflexions of the "rosette," each then divaricating into two branches, which enter the two adjacent orifices on the internal face of each pair of first radials, as described in my former Memoir. All these cords were described by Müller as vessels; I am satisfied, however, that they are not tubular, but solid.—On making a transverse section of the hollow organ it is found to contain five chambers (fig. 4), clustered like the carpels of an orange round a central axis; and near this axis each chamber seems to communicate on its ventral aspect with the surrounding space (an extension of the perivisceral cavity) by a minute orifice (*d*) in its wall. Within the dorsal portion of this organ, lying at the bottom of the centro-dorsal basin, there is a succession of verticils of five triangular leaflets (fig. 5, *a*), increasing in size from below upwards, from the extremities of some of the upper of which leaflets issue groups of three diverging cords that proceed to the cirrhi. I can scarcely doubt that these verticils mark the origins of the earlier cirrhal cords from the Crinoidal axis; and this obviously suggests that the five-chambered organ is itself only another and larger verticil, which has come, by the formation of ventricular cavities in its substance (analogous to the lateral ventricles of the brain), to occupy the whole cavity of the enlarged centro-dorsal basin.

This view, which deprives the chambers of the five-chambered organ of any special physiological significance, is confirmed by what I have ascertained of the structure of the Crinoidal axis which occupies the interior of the stem of the true *Pentacrinus*. This has a central portion quite distinct from the peripheral portion, which forms a cylindrical sheath around it. It is from the cylindrical sheath that at every node of the stem there pass off five cords into the whorls of cirrhi or "auxiliary side arms;" and at every node there is a slight dilatation of the cylinder, which is caused, not by a thickening of the substance of the axis, but by a separation between its central and its peripheral portions—foreshadowing the great ventricular dilatation just described at the summit of the axis of *Antedon*. In *Pentacrinus*, which has no cirrhi attached either to the uppermost part of the stem or to the base of the calyx, there is neither enlarged centro-dorsal cavity nor special dilatation of the Crinoidal axis.

The divaricated cords which enter the First Radials form a sort of "Circle of Willis" within the system of canals completed by their lateral adhesion, as described in my former Memoir (§§ 34, 77); and from this circle there issue five *radial cords*, which speedily divaricate into ten *brachial cords* that pass continuously through the *centra* of the segments of the arms.

This apparatus (consisting of the outer cylinder of the Crinoidal stem, of the five-chambered central organ formed by the dilatation of that axis within the centro-dorsal basin, and of the cords proceeding from it to the arms and cirrhi) I regard as the central portion of a *nervous system*; and I shall hereafter draw what seem to me conclusive proofs that such is its character, both from the distribution of branches of the brachial cords to the muscles of the arms, and from the effect of irritation of the central organ in the living animal, even after its complete evisceration, in causing the sudden and general contraction of those muscles (p. 226).

Axial Prolongation.—I now follow the course of the central or medullary portion of the Crinoidal axis, which passes continuously upwards through the middle of the quinquelocular dilatation of its cortical cylinder (as shown at *g*, *h*, fig. 3), just as in a flower the axis which forms the style of a multilocular ovary passes upwards through the midst of the carpels which are clustered around it. In the upward course of this "axial prolongation," as it may be provisionally termed, it first passes through the central aperture of the "rosette," and then through the vertical canal which is left by the truncation of the wedge-like First Radials, thus reaching the base of the cavity of the calyx, and constituting the "pedicle," of which I have already spoken, as the chief attachment existing between the basal (or dorsal) surface of the lenticular visceral mass and the concavity of the calyx. This "pedicle" (*h*, fig. 2) enters the "axial canal" (*g*) previously described as passing upwards towards the oral pole, and may be traced along its whole length (generally more or less imbedded in its wall) to the point at which that canal subdivides into the five subtentacular canals which underlie the radial furrows of the disk. Here the axial cord appears to spread out into a plexus which surrounds the mouth; and this plexus is continued towards the periphery of the disk underneath the radial and brachial canals, every one of which usually has a cord running along each of its margins, connected by transverse branches with the cord of the opposite side. At or near the margin of the disk the two cords of each brachial canal seem to coalesce into a single one; and this runs onwards between the subtentacular and the cœliac canal of the arm (as shown at *gr*, fig. 6), giving off branches which pass into the sexual pinnules; and these branches are continuous with the testes or ovaries which these pinnules contain.

Hence it would appear that this "axial cord" is (in part, at least) a *generative rachis*, furnishing the germs which are to be developed into the proper sexual products; and this view I find to be confirmed by minute examination of its structure. At the point at which it dilates into the cavity of the ovary, it is clearly a tube containing minute corpuscles of about 1-3000th of an inch in diameter; and from these corpuscles to complete ova every stage can be traced. Following the cord backwards towards the plexus of the disk, I find it still to possess the same tubular wall and granular contents; in the plexus itself the cavity with its granular contents bears a smaller proportion to the thickness of the tubular wall; but the "axial prolongation," from which I believe this plexus to arise, often seems at the period of generative activity to be almost made up of such corpuscles.

I confess that I have not yet been able to trace the absolute continuity of the generative plexus of the disk with the axial cord of the adult *Antedon*, the dissection of the parts around the mouth being made very difficult by the quantity of loose connective tissue which forms the annular lip. The termination of the axial prolongation and the origin of the plexus in the same locality obviously point to such continuity; but

I shall show it to be almost unmistakably established by the history of embryonic development, at a certain stage of which the subdivision of the axial prolongation (*ax*, fig. 11) into diverging branches, of which one passes to each ray, is very distinctly traceable.

Arms.

Each Arm is composed of a linear series of calcareous segments, connected with each other by muscles and elastic ligaments, in the manner described in my former Memoir, the muscles being all *flexor*, whilst the ligaments are *extensor*. Thus when the muscles (of which a pair intervenes between each segment and its proximal and distal segments, except where two segments are connected by a syzygy) are called into contraction the arm is coiled up spirally like a watch-spring, whilst when the muscles relax it is straightened out again by the elasticity of the ligaments. —What may be called the *centrum* of every one of the calcareous segments is perforated by a circular foramen (*a a*, fig. 6); and the linear succession of these foramina forms a canal, which is occupied by a cord of protoplasmic substance (*b*) given off from the circlet contained within the first radials, which circlet (as already described) is formed by the lateral inosculation of the five radial cords (*l*, *m*, fig. 3) given off from the five-chambered organ (*g*) contained within the centro-dorsal basin. I have occasionally found, in transverse sections of decalcified arms (especially in *Antedon celticus*), pairs of branches given off from this "axial cord" at the junction of the segments to ramify upon the muscles; and it was this anatomical fact which suggested to me that the "axial cord" has really the function of a *nerve*, although not possessing its characteristic structure, and that the five-chambered organ must consequently be a nervous centre. That the cord which was supposed by Müller to be a nerve has an altogether different function, was stated in my previous Paper (§ 19), on the basis of the connexion I had even then demonstrated between that cord and the generative organs developed in the pinnules. And the nerve-function which I then, on anatomical grounds alone, attributed to the axial cord has been since completely borne out by the experiment to be presently cited.

Along the upper or oral face of the succession of calcareous segments with its intervening muscles there lies a single large canal (*cc*, fig. 6) occupying the whole breadth of each arm; this is the *cœliac* canal already spoken of as an extension of the lower part of the *cœlom* or perivisceral cavity (*cc*, fig. 12). Enclosed on either side by the perisome, it is shut in at the top by a transverse partition that separates it from the double subtentacular canal (*stc*, *stc*, fig. 6) which overlies it. This double canal is virtually single; for the vertical partition which divides it has large irregular openings (fig. 7), which allow a free communication between the two lateral halves*. Where this vertical partition joins the horizontal partition separating the cœliac from the subtentacular canals, a longitudinal passage is left (which may be called the genital canal), in which lies what I have shown to be the generative *rachis* (fig. 6, *gr*), as Prof. Semper independently discovered. Where, again, this vertical partition joins the thickened layer of perisome which forms the floor of the inter-tentacular groove, there is a small circular canal (overlooked by Müller and every other anatomist), which is the real *tentacular* canal (*tc*, figs. 6, 8, 9), its continuity with the interior of the tentacles being very distinctly visible both in transverse and in longitudinal sections. The latter show a single oval orifice (*oo*, fig. 9) opening out of the tentacular canal for each group of three tentacles.

---

* In some species of *Antedon* this canal is actually as well as virtually single.

The perisome covering the oral surface of each arm exhibits a continuation of the brachial furrow formed by the divarication of the radial furrow of the oral disk, each side of this furrow being bounded, as in the disk, by successive groups of tentacles, and by an elevated fold of the perisome, scolloped at its edge so as to form a row of minute valvules, like those of the oral disk, beyond which, when the tentacles are extended, they project considerably, but within which they may be withdrawn, so that the two folds may close down, the valvules meeting in a sinuous line so as completely to cover the furrow.—The floor of the furrow is formed by the peculiar layer which, as already stated, I regard as a columnar epithelium; its free surface I believe to be clothed with minute cilia, the direction of whose movement is from the periphery towards the centre; there are, however, no cilia on the tentacles. These points, correctly stated by M. Edmund Perrier, I had worked out soon after the publication of my previous Paper.

Pinnules.—Every segment of the arms bears a pinnule; and the pinnules are disposed alternately along the two sides of each arm. Their calcareous segments are united by ligaments alone; but each centrum (*a*, figs. 8, 9) is perforated as in the arm, and contains a branch (*b*) of its axial cord. On the oral face of the succession of calcareous segments there lies an extension (*cc*, figs. 8, 9) of the *cœliac* canal of the arm; and immediately above this, in the barren pinnules, lies a single *subtentacular* canal coming off from the lateral division of the double canal of the arm which belongs to the side that bears the pinnule. In the thickness of the horizontal partition between these two canals there is a passage left by a separation of their walls, in which lies a lateral branch of the generative *rachis*. The true *tentacular* canal (*tc*, figs. 8, 9) lies, as in the arms, along the oral face of the subtentacular canal. The first pinnules of each arm, however, are differentiated from the rest by the absence of tentacles, and likewise by the greater number and closer setting of the peculiar sacculi (*ss*, figs. 6, 8) contained in the perisomal folds which bound the radial furrow.

When the tumefaction of a pinnule shows either the testis or the ovary to be developed in it, this organ is found to lie between the cœliac and the subtentacular canal, completely separating the one from the other (figs. 6, 8); and it was this correspondence of position which first suggested to me the real nature of Müller's "nerve." On tracing the testis or ovary to the base of the pinnule, I clearly made it out to have the same relation to the lateral branch of the generative *rachis* of the arm (*h*, fig. 9) as the currants forming a bunch have to the stalk that bears them; and if I am correct in deriving the generative rachis from the "axial prolongations," it may be considered originally to spring from the Crinoid Axis itself.

Towards the extremities of the pinnules, especially in those that contain no generative organs, the horizontal partition between the *cœliac* and *subtentacular* canals thins away, and at last becomes obsolete; so that at the periphery of this canal-system there seems to be as free a communication between the two sets of canals as there is between the arteries and veins of the higher animals through the capillary plexus. And, for reasons to be presently given, I feel strongly inclined to believe that a regular circulation is carried on through them, the nutritive fluid being transmitted through one set of canals from centre to periphery, then passing into the other, and being conveyed by it back from periphery to centre.

PHYSIOLOGY.

Ingestion of Food.—That the food of *Antedon* consists, not of the large bodies grasped and swallowed by ordinary Starfish, but of minute and even microscopic organisms, and that the so-called "tentacles" are entirely destitute of prehensile power, was long since affirmed by Dujardin on the basis of observation of the habits of the living animal and of microscopic examination of the matters ejected from the vent. These statements are entirely borne out by my own careful observation of the actions of the brachial and tentacular apparatus, alike in the Pentacrinoid and in the adult condition, and by the microscopic examination I have repeatedly made of the contents of the alimentary canal. These consist of minute Entomostraca, Diatoms, spores of Algæ, &c., but especially, in my Lamlash specimens, of *Peridinium tripos* (Ehr.), which was usually very abundant in that locality. A powerful indraught current towards the mouth is maintained by the action of the large cilia that fringe the villous folds of the alimentary canal; but this does not extend to any considerable distance; and it is clear that minute particles are transmitted from the peripheral extremities of the arms and pinnules, along the brachial furrows and the radial furrows of the disk, to the neighbourhood of the mouth, where they come within the reach of the oral indraught. This I have repeatedly seen when I have had young Pentacrinoids alive under the microscope; and although I have been prevented, by the peculiarity of their position, from detecting the cilia to which the transmission is attributable, I can scarcely doubt that they belong to the epithelial floor of the furrows. And when I have detached small pieces of the soft parts from the arms of the living adult, I have found currents to be produced in the water surrounding them, which could only be accounted for by ciliary action. Thus the brachial apparatus may be regarded, in the first place, as an extended food-trap.

It may be here added that my examination of various types of existing *Pentacrini* enables me to affirm that they are nourished in exactly the same manner, their brachial and digestive apparatus being constructed upon precisely the same plan as that of *Antedon*, and the contents of the alimentary canal being of the like nature. And this renders it probable that not only the *Pentacrini* of the Mesozoic period, but the entire series of *Crinoids* extending through the whole range of geological time, from the "primordial zone" of Barrande to the present epoch, obtained their food after the like fashion.

In the thickened disk which surrounds the mouth, formed at the junction of the perisome of the oral disk with the wall of the alimentary canal, I have detected a series of cæcal tubuli opening into the commencement or œsophageal portion of the alimentary canal; these may have a *salivary* function. And the peculiar gland-like character of the plicated portion of the wall of the inner side of the horizontal coil of the alimentary canal seems to render it probable that it performs the function of a *liver*.

Circulating and Respiratory Apparatus.—It has been shown that the true "tentacular" canals constitute a system entirely distinct in the adult from the general canal-system of the arms, although derived like it, in the first instance, from the perivisceral cavity, and that there is no proper oral ring which can be regarded as the centre of the radiating tentacular canal. As it has also been shown that the so-called "tentacles" have no share whatever in the ingestion of food, the question arises, what is their function in the economy of the animal? I am disposed to think that they are homologous with the tentacular fringe surrounding the mouth of the *Holothurida*, and with the "respiratory tubes" of the *Asterida* and *Echinida*, and that they constitute a special respiratory apparatus, serving for the aëration of a fluid that may be regarded, like the red blood of a *Terebella*, as not so much nutritive as respiratory*. It is no objection to this view that the tentacles of *Antedon* are not ciliated on their surface; for this is true also of the branchial tufts of *Terebella* and other *Annelids* having a double respiratory apparatus, one for the red blood, and the other for the "chylaqueous" fluid. Certain it is that *Antedon* is more dependent than Echinoderms generally upon the perfect aëration of its fluid, as it soon dies in water that is not kept in a state of tolerable purity, though *Ophiuræ* and *Ophiocomæ* may thrive in it.

---

* It is stated by M. Edmund Perrier that distinct muscular fibres are traceable in the walls of the tentacles; and these may produce a sort of vermicular contraction by which the fluid of this canal-system is kept in movement.

It has further been shown that, besides the tentacular canal-system, each arm and pinnule contains two canals, one superposed on the other, communicating at the termination of the pinnules, and that while the lower or *cœliac* canals open directly into the deeper portion of the cœlom or perivisceral cavity, the upper or *subtentacular*, passing inwards as the radial canals of the oral disk, become continuous with the upper part of the "axial canal," which opens at its lower end into the deepest part of the cœlom. Thus a complete continuity, alike central and peripheral, is established throughout the whole of this space; and the central canal also receives what may be termed the "mesenteric sinuses" proceeding from the plications of the internal wall of the alimentary cavity. Thus it seems probable that the products of digestion, except such as may transude directly through the double wall of the alimentary canal into the cœlom, are collected into these mesenteric sinuses, and by them conveyed into the axial canal, and that from this centre the nutritive fluid is circulated throughout the double system of canals, passing from one to the other, centrally through the axial canal, and peripherally at the extremities of the pinnules. I have distinctly seen a movement of granular fluid in one of the canals of the arm of a Pentacrinoid, proceeding from the extremity towards the centre; and although I was unable to distinguish with certainty in which of the canals it took place, my impression is that it was the cœliac. If this be so, the *subtentacular* canals constitute the *arterial* or distributive, and the *cœliac* canals the *venous* or collective, system. Now as the axial canal is bounded by a columella strengthened by the piling-up of calcareous plates, its walls can scarcely be supposed to have any contractile power; whilst, on the other hand, as the surface of the peritoneum lining the cœlom is ciliated in other Echinoderms, it may be presumed to be so in *Antedon*: and thus we may fairly surmise that the circulation is kept up by ciliary movement. —If sea-water be admitted, as I believe it to be, through the ciliated funnels of the oral perisome, into the cavity of the cœlom, the circulating fluid will correspond in its mixed character to the "chylaqueous" fluid of many aquatic Invertebrata.

One important office of this circulation will obviously be to supply nutritive material for the periodical development of the sexual apparatus; and no arrangement could be conceived more conducive to such a purpose. For in the pinnules, whose turgidity indicates the enlargement of the generative *rachis* into testes or ovaries (as the case may be), these organs (as shown in figs. 8, 9) lie between the two thin-walled canals, so that they can readily draw nutrient fluid alike from the going and from the returning current. It can scarcely be doubted that the "chylaqueous" fluid is aërated during its transmission through the canals of the arms and pinnules, particularly as the clothing of very minute cilia which I have detected on the dorsal side of the arms will serve to renew the stratum of water in contact with them.

Thus we are also to regard the arms and pinnules in the light of a *respiratory* apparatus, an interchange of gases between the contents of the canals and the surrounding medium being promoted by the subdivision of the canals and the consequent extension of their surface.

Nervo-muscular Apparatus.—In the First Part of my Memoir I described the manner in which the contraction of the pairs of muscles intervening between the vertical lamellæ rising from the oral faces of the successive calcareous segments of each arm coils it up into a spiral, the uncoiling being produced, when the muscles relax, by the elasticity of the ligaments interposed between the segments near their dorsal margins. The coiling and uncoiling often take place through the whole length of the arm, with a quickness and consentaneousness which has no parallel in the comparatively sluggish and limited movements of other Echinoderms; and while a single arm may be made to coil up by irritating one of its pinnules, the whole circlet of arms closes together when an irritation is applied to the pinnules which arch over the mouth, an act which affords a strong indication of the "internuncial" action of a definite nervous system. The anatomical considerations already specified having led me to the conclusion that the radial cords which pass through the calcareous segments of the arms are really nerve-trunks, and that the five-chambered organ in the centro-dorsal basin is their centre, I put their character to the following experimental test, when visiting Oban in the autumn of 1867:—Having completely eviscerated a living specimen, so that nothing was left but the calyx and arms, with the centro-dorsal basin and its contents, I passed a needle down through the canal left at the base of the calyx between the central faces of the first radials, so as to irritate the quinquelocular organ beneath; all the ten arms then suddenly and consentaneously closed up. On the withdrawal of the needle, the arms gradually straightened themselves again, and again coiled up as before when the irritation of the central organ was renewed. I am at a loss to see in what respect the evidence thus afforded that this organ is functionally a nerve-centre, and that the radial cords are nerve-trunks, is less cogent than that which we draw from the contraction of the limbs of a Vertebrate animal when we irritate the segment of the spinal cord which gives off their nerves. The chief difficulty in assigning to them such a function arises from their want of the histological characters of nerves. The radial cords, hardened in strong spirit, may be torn into fibrils of extreme minuteness; but, so far as I have yet been able to ascertain, these fibrils have a homogeneous protoplasmic composition. This absence of differentiation may, as it seems to me, be related to the fact that as the muscles are all flexors, the nerves have only one function to perform, and that there is consequently no need of the insulation which they require where nerve-fibres of very different functions are bound up in the same sheath.

The curious little saccular organs (*s s*, figs. 6, 8) which lie at intervals along the outside of the ridges that border the tentacular furrow in the arms and pinnules, and which, by their peculiar property of attracting the colouring-matter given off after death by other parts of the body, become the well-known "red spots," have long been a puzzle to students of *Antedon*. I have long been myself inclined to regard them as Sensory organs, my surmise being founded on the fact that in the oral pinnules, which have no tentacular apparatus, but which are much more irritable (*i. e.* more susceptible of impressions which call forth contraction of the arms) than the tentaculiferous pinnules, these sacculi are crowded together so as to form two continuous rows*.

DEVELOPMENT.

In the earliest stage at which I have been hitherto able to study the Pentacrinoid larva (which may be designated as "Allman's stage†"), the calyx rather resembles an inverted bell than a shallow basin, its lower part being supported by the five basals, whilst its upper is surrounded by the five incipient first radials which alternate with them. Alternating in position with the five first radials, and at this stage resting immediately upon them, are five oral plates, somewhat triangular in form, enclosed in valvular folds of the delicate perisome which forms the general investment of the body. These oral valves, when inclined towards each other, form a sort of five-sided pyramid, which completely covers in the oral disk; but when opened out they surround it like the expanded petals of a flower. Immediately within the oral valves is a thin elevated lip, from which spring the oral tentacles; and the wide mouth, leading into a funnel-shaped œsophagus, occupies the whole of the area surrounded by this lip. A vertical section of the calyx in this stage shows the gastric sac loosely suspended in the perivisceral cavity or *cœlom* (*pv*, fig. 10), with the inner wall of which, however, the outer wall of the gastric sac is connected by scattered threads and lamellæ of connective tissue. And it is very distinctly seen that the circular lip is formed by an annular plication of the bounding membrane of the perivisceral cavity, a space being left between the two folds, which constitutes the original tentacular or ring-canal, *rc*. Hence this tentacular canal is clearly a derivative of the *cœlom*, the only separation between them at this stage consisting in a circlet of threads of connective tissue, which passes between the inner and outer folds of the lip. The increased development of this connective tissue subsequently constitutes a partition that cuts off the oral ring from the *cœlom*, and finally breaks up the canal itself into an irregular areolation.

The gastric sac at this stage is elongated horizontally into a form somewhat resembling that of the human stomach, having a "large end" into which the funnel-shaped œsophagus opens obliquely, and a "small end" with a cæcal termination (*an*, fig. 10), which is the original intestine. To the middle of this gastric sac, in sections which exhibit it *in situ*, the "axial prolongation" may be distinctly seen passing up from the base of the calyx. The wall of the gastric sac is everywhere thick, and is chiefly composed of a yellow substance which appears to consist of a layer of columnar epithelial cells, the free surface of which layer is clothed with cilia.

---

* They have been carefully studied by M. Edmund Perrier (*loc. cit.*), who has corrected (as I had long since privately done) the mistake into which Prof. Wyville Thomson fell in regarding the corpuscles they contain as calcareous, but has not thrown any further light on their function.

† See his Memoir in the Edinb. Trans. Roy. Soc. vol. xxiii. (1861), p. 241.

The further development of the alimentary canal consists, in the first place, in the prolongation of the intestinal extension of the gastric sac—this prolongation at first taking place horizontally, so that the intestine coils round the stomach in the space left for it by the enlargement of the calyx. Later on, as the second and third radials are developed and the cavity of the calyx opens out, while the circlet of oral valves undergoes very little enlargement, there comes to be a space between the outside of that circlet and the inside of the circlet of incipient arms; at one point of this space a projection of the perisome shows itself, enclosing a single thin oval calcareous plate; and towards this projection the cæcal termination of the elongating intestine directs itself upwards. At last it reaches the prominence of the oral disk, and opens upon its surface, forming the projecting vent.—The manner in which the axial canal is formed by the gradual limitation of the space left by the coiling of the intestine round the stomach (*al*, fig. 11) is shown very clearly in this and the succeeding stages; and I have been fortunate enough to trace the axial prolongation (*ax*) upwards through this space, from the base of the calyx to its subdivision, by the side of the œsophageal funnel, into five radial branches.

The extension of the oral ring into the radial and brachial tentacular canals having been minutely described by Prof. Wyville Thomson, I need not go over the same ground; but I have now to speak of the origin of the subtentacular and cœliac canals.

From the time when the intestinal coil is formed, and its anal termination opens on the surface of the disk, the growth of the alimentary canal goes on at a greater rate than the enlargement of the calyx; and the consequence is that the marginal portion of the intestine comes into such close contact with the lining of the calyx, as to divide the cœlom into an upper or oral and a lower or dorsal portion* (fig. 12); and this division is completed by the membranous fold, *mf*. From each portion there passes a sort of digitate extension into every ray, each extension having its own lining membrane. The communication of the lower extension, forming the cœliac canal (*cc*, fig. 12) of the rays and arms, with the ventral division of the cœlom always remains freely open; but that of the upper or oral extension forming the subtentacular canals (*stc*) of the rays and arms, with the oral division of the cœlom itself, is gradually limited by the enlargement of the visceral mass, and by the formation of adhesions between its upper surface and the under surface of the oral disk; so that, as the vertical communication between the upper and lower divisions of the cœlom becomes gradually narrowed into the "axial canal," so the oral portion of the cœlom may be said to become gradually narrowed into the subtentacular canals of the disk.

---

* This has been distinctly recognized by Metschnikoff, who also has pointed out (what had long since occurred to myself) that the relation of the visceral and tentacular apparatus to the two divisions of the perivisceral cavity remarkably corresponds ʻʻh that which prevails in many Polyzoa.

The principal changes of note which occur in the further development of the visceral mass consist in the progressive infolding of the wall of the alimentary canal on the central side of the tube, so as to form the gland-like projection into its cavity; the development of the calcareous disks in the inner or mucous layer of that wall, the piling-up of which in its infolded portions constitutes the "columella;" the separation of the outer or peritoneal layer from the mucous, forming a space which is crossed by multitudinous threads and lamellæ of connective tissue; the narrowing of the spaces formed by the infolding of the walls of the alimentary tube into the mesenteric canals which open into the axial canal; and, generally, the development, in various parts, of a large quantity of connective tissue, which traverses what would otherwise be vacuities, and gives compactness to the whole "visceral mass."

The mode of development of the peripheral portion of the summit of the original Crinoidal axis into the quinquelocular organ contained within the centro-dorsal plate has been already noticed; and as I described in my former Memoir the very curious manner in which its radial cords, which at first lie on the upper or ventral side of the basal plates, finally come to lie on the lower or dorsal side of the "rosette" formed by their metamorphosis, I need not here repeat the history.

EXPLANATION OF THE PLATES.

Plate 8.

Fig. 1. Horizontal Section of the Visceral mass of *Antedon rosaceus* (after decalcification of the skeleton), laying open the intestinal coil:—*a*, termination of the oblique or œsophageal portion in the horizontal or intestinal portion *b*, *c*, which forms a *cul-de-sac* at *d*, where it abruptly bends upwards to form the projecting vent; at *g* is seen the axial canal, surrounded by the columella formed by the infolding and duplication of the intestinal wall; *f*, connective tissue and interspace-system, shown at *e* to be an extension of the space between the two lamellæ of the intestinal wall.

Fig. 2. Vertical Section of the Calyx:—*a*, mouth, surrounded by oral ring, and surmounted by the two tentaculiferous lobes *m m*; at *b* is seen the oblique or œsophageal portion of the alimentary canal, the horizontal or intestinal coil of which is transversely divided at *c* and *d*, showing in section the corrugations of its double wall, the internal surface of which is covered by a thick (hepatic?) epithelial layer, *e*, *f*. At *g* is seen the lower part of the axial

canal, containing a portion of the axial prolongation *h*. The middle part of this canal communicates on either side with the interspace-system formed by the infolding of the double wall of the alimentary canal; and at *l* is seen in transverse section, opening into the summit of the axial canal, one of the radial subtentacular canals of the ventral disk. On the other side of the mouth are seen two of the brachial subtentacular canals, one of them transversely divided at *i*, and the other obliquely divided at *k*, about to coalesce into a radial canal which passes round the œsophagus to open into the axial canal.—This section has not laid open the quinquelocular organ in the centro-dorsal basin; but from its lower or dorsal margin several small cords, *l*, are seen to pass off to enter the dorsal cirrhi.

Fig. 3. Vertical Section of the Calyx, through a different plane from the preceding:—*a, b, c, d, e, f* as in the last figure; *g*, quinquelocular organ; *h*, lower part of the axial prolongation, springing from the central axis of the quinquelocular organ, and passing behind one of the extensions of the glandular reduplication, to reappear above it at *h'*, proceeding to the circular lip seen in section at *i*; at *k* is shown the mass of connective tissue with its interspace-system lying between the duplications of the intestinal wall that form the columella; *l, m*, two of the axial (nerve?) cords proceeding to the rays from the upper or ventral margin of the quinquelocular organ.

Fig. 4. Transverse Section of the Quinquelocular organ, viewed from its upper or ventral aspect:—*a*, central axis formed by a prolongation of the axis of the Crinoidal stem; *b, b*, dissepiments forming five ventricular cavities; *c, c*, one of the axial verticils sending off cords that seem to pass through the peripheral wall to proceed to the dorsal cirrhi; *d, d*, apertures by which the five ventricular cavities communicate with the perivisceral space.

Fig. 5. Vertical Section of the Quinquelocular organ, showing the division of its upper or ventral portion *b* into chambers, and the occupation of its lower or dorsal portion *a* by a succession of axial verticils giving off cords to the cirrhi.

PLATE 9.

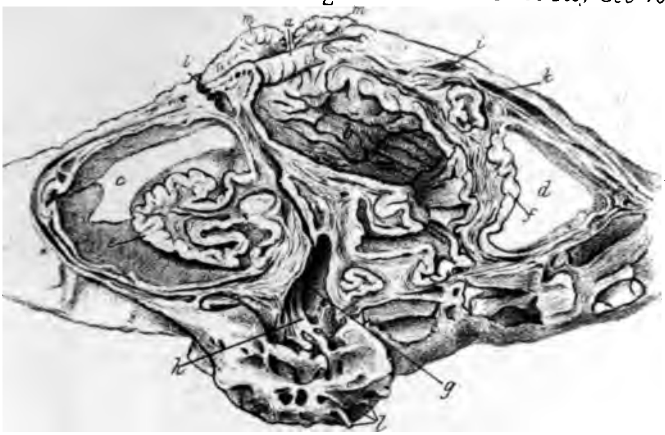
Fig. 6. Transverse Section of decalcified Arm:—*a, a*, organic basis of calcareous segment; *b*, solid axial (nerve?) cord proceeding from quinquelocular organ; *m, m*, muscles; *cc*, cœliac canal; *gr*, tubular genital rachis (the nerve of Müller), lying in its genital canal; *stc*, the two subtentacular canals (the tentacular canals of Müller), which virtually form a single canal, the partition between them being cribriform, as shown in fig. 7; *tc*, the true tentacular canal, giving off alternating lateral branches to the tentacular apparatus and the crescentic folds, at the base of which lie the saccular (sensory?) organs *s s*.

Fig. 7. Longitudinal Section of the ventral portion of the Arm:—*cc*, cœliac canal, giving off at *d d* lateral branches to the pinnules; *stc*, subtentacular canal, divided from its fellow by cribriform partition. The section has not laid open the true tentacular canal; but the orifices by which it communicates with the tentacular system of the near side are seen at *t t*, and those leading into the bases of the groups of tentacles of the off side are seen at *t' t'*.

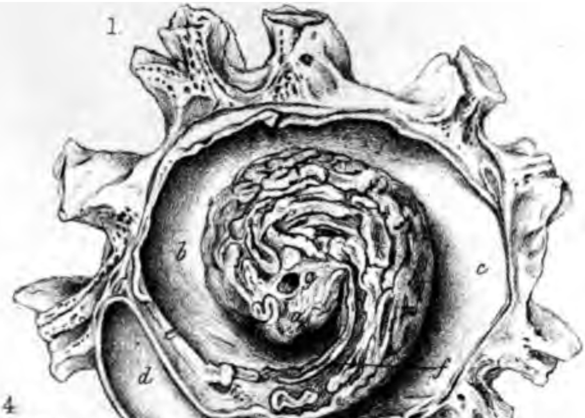
Fig. 8. Transverse Section of decalcified Spermatigerous Pinnule:—*a*, organic basis of calcareous segment; *b*, axial cord; *cc*, cœliac canal; *t*, testis, lying within a dilatation of the genital canal *gc*, and developed (like the ovary shown in fig. 9) from a peduncle given off from the genital rachis; *stc*, single subtentacular canal; *tc*, true tentacular canal; *s s*, saccular (sensory?) organs.

Fig. 9. Longitudinal Section of decalcified Ovigerous Pinnule:—*a a*, organic basis of

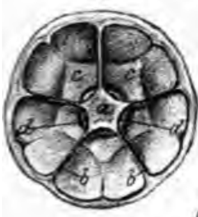
2



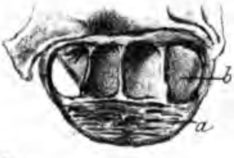
1.



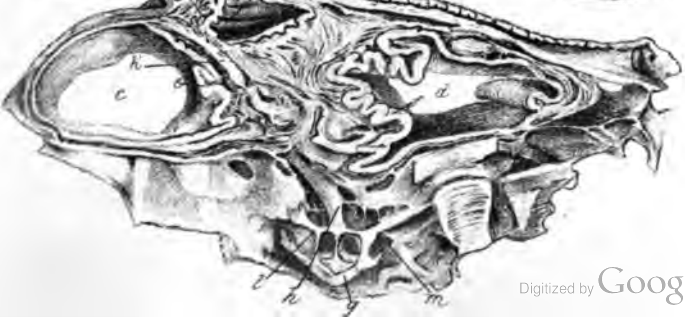
4



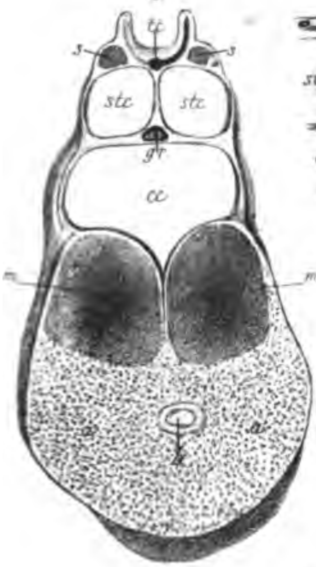
5



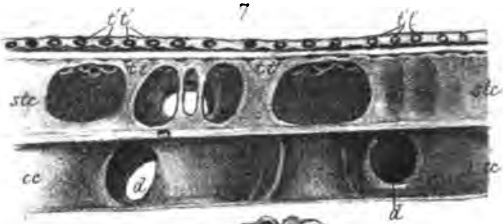
3



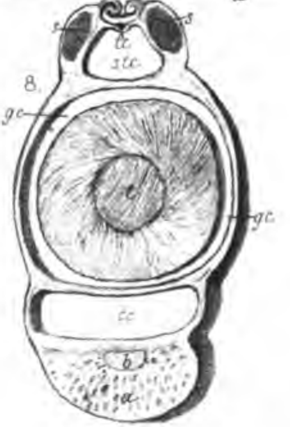
6


tc
s
s
stc
stc
gr
cc
m
m
a
a
b

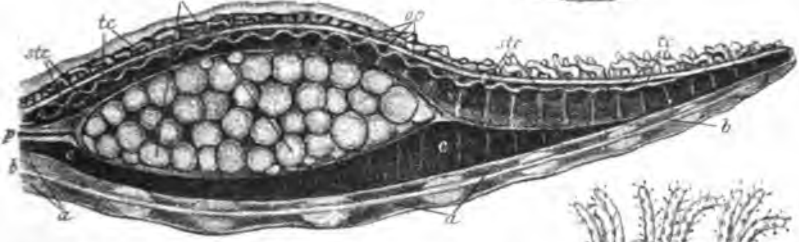
7


t't'
t't'
tc
tc
stc
stc
cc
d
tc
d

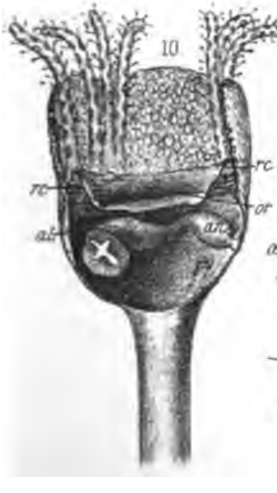
8.


s
s
tc
stc
gc
c
gc
tc
b
a

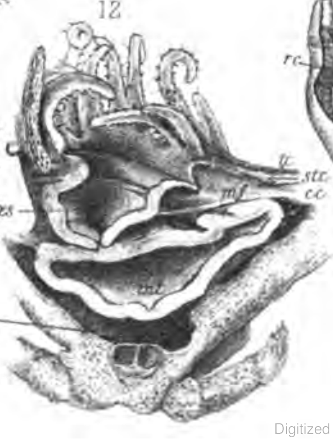
9.


ov
tc
ov
stc
stc
tc
p
c
b
b
a
d

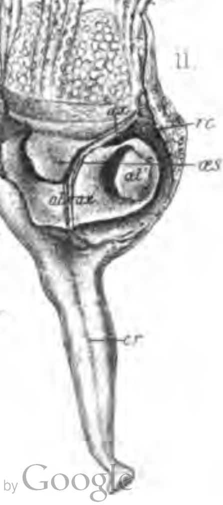
10


rc
rc
or
al
an

12


tc
stc
œs
mf
cc
int

11.


rc
ax
rc
œs
al'
alv.ax.
cr

calcareous segments; *b*, axial cord; *c c*, cœliac canal, extending to near the extremity of the pinnule; *ov*, ovary filling the dilatation of the genital canal, and developed from the peduncle *p* given off from the genital rachis of the arm; *stc*, subtentacular canal; *tc*, true tentacular canal, with its orifices, *o o*, leading to the tentacular apparatus.

Fig. 10. Vertical Section of a very young Pentacrinoid, showing a portion of the Alimentary canal *al*, hanging freely in the large perivisceral space *pv*, and the formation of the ring-canal *rc* from which the tentacles proceed, by the marking-off of the portion of the space included in the fold of the oral disk *or*, by transverse threads of connective tissue. At *an* is seen the cæcal termination of the intestine, not yet bending upwards to protrude as a vent.

Fig. 11. Vertical Section of a somewhat more advanced Pentacrinoid, in which the development of the Arms has not yet commenced, showing the enlargement of the Alimentary canal *al* divided transversely at *al'*, and the relative diminution of the perivisceral space; the crinoidal axis of the stem *cr* is seen to be prolonged upwards at *ax*, through the central space left within the intestinal coil, and to pass obliquely along the œsophageal portion *œs* of the canal towards the oral ring-canal, *rc*.

Fig. 12. Vertical Section of a Pentacrinoid in which the Arms and Dorsal Cirrhi have appeared:—the alimentary canal, of which *œs* is the œsophageal portion, and *int* the intestinal portion, now fills the perivisceral cavity more completely; and a membranous fold *mf* shows itself, which divides that cavity into a dorsal and a ventral portion. From the former proceeds the cœliac canal *cc*; from the latter the subtentacular canal *stc*; while the true tentacular canal *tc* proceeds from the oral ring-canal, which is still not blocked up by the cæcal tubuli and connective tissue that subsequently occupy it.

January 27, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Variations of the Daily Mean Horizontal Force of the Earth's Magnetism produced by the Sun's Rotation and the Moon's Synodical and Tropical Revolutions." By J. A. Broun, F.R.S. Received December 15, 1875.

(Abstract.)

The variations of daily mean horizontal force in the years 1844 and 1845 showed several well-marked oscillations, having periods of from 20 to 30 days, and amplitudes, in some cases, of more than one thousandth of the whole magnetic force. These oscillations were first attributed to lunar action; afterwards they were found more probably due to the sun's rotation on his axis. The disappearance of these oscillations in

the middle of well-marked series, their different amplitudes and periods, could not be explained except by the supposition that the solar action was not continuous, but only by fits periodic.

The author was induced to believe lately that these differences in the oscillations were due to conjoint actions of the sun and moon; he accordingly deduced the mean variations corresponding to three periods of 26, 29·5, and 27·3 days, the times of rotation of the sun derived from the magnetic observations, and of the moon's synodical and tropical revolutions respectively. He finds that the combinations of these three series of variations represent with considerable accuracy all the variations of the daily mean horizontal force of the earth's magnetism during each year; so that the sun's rotation and the different positions of the moon relatively to the sun and the plane of the equator (or of the ecliptic) are found to produce all the differences in the amplitude and time, as well as the apparent disappearance of the oscillation.

Cases of considerable and sudden diminution of the earth's magnetic force which happened in the years 1844 and 1845 are next examined; and it is shown that these changes occur at intervals of 26 days, or multiples of 26 days; in one instance there are five successive recurrences at the exact interval of 26 days.

As this period is that of the sun's rotation *relatively to the earth*, it appears to follow that the earth has some action on the sun, or (more probably) on some ray-like emanation from the sun, which causes these changes in the earth's magnetism.

It is found also that these sudden variations occur more frequently when the moon is at a considerable distance from the equator and the ecliptic; it would thus appear that our satellite has also an action on the cause of the great terrestrial magnetic disturbances.

II. "Results of the Monthly Observations of Magnetic Dip, Horizontal Force, and Declination made at the Kew Observatory from April 1869 to March 1875 inclusive." By the KEW COMMITTEE. Received November 25, 1875.

This paper, containing the result of six years' magnetic observations at the Kew Observatory, follows as the third of a series of publications, the first of which was a communication to the Royal Society by General Sir E. Sabine, published in the Philosophical Transactions for 1863, page 273, which consisted of a discussion of certain selected magnetic disturbances, a general discussion of declinational changes as recorded by the magnetographs, and a discussion of the absolute determination of Dip and Horizontal Force at the Observatory, for the six years April 1857 to March 1863 inclusive.

The second publication appeared in 1870 as a paper in the 'Proceedings of the Royal Society,' contributed by Dr. Balfour Stewart, the Superintendent of the Observatory; it contained the results of the monthly observations of Dip and Horizontal Force for the next series of six years, viz. from April 1863 to May 1869.

There is now presented a further series of six years' observations of Dip and Horizontal Force, from April 1869 to March 1875 inclusive, together with observations of absolute declination for the same period.

The instruments employed in the determinations are the same as those described by Sir E. Sabine in the Philosophical Transactions, 1863, page 296, no change worth noticing having been made in either instruments or magnets.

As in the case of the six years discussed by Dr. Stewart, only those dips have been considered which have been made with the two needles Nos. 1 and 2 of circle Barrow No. 33; of these the general practice has been to observe both needles on two successive days in the middle of the month, giving the mean of the four observations as the mean for the month.

The values of the constants employed in the reduction of the observations of vibration and deflection have been redetermined, and found to closely correspond with those found by Mr. Welsh, which are given in the paper quoted above.

Two observations of vibration and two of deflection, at two distances, have been made each month, the mean result being taken as the force for the month.

The Declination observations have been made in the Magnetic Observatory with the Kew 9-inch unifilar and a reversible collimator magnet NE, the instrument being directed after each reading to the reference-marks on the obelisk erected a quarter of a mile to the north of the Observatory as a meridian mark for the transit instrument.

The azimuth of this mark, as viewed from the declinometer, was carefully determined by Mr. Welsh in 1857, and has since been verified both by Mr. Chambers and Mr. Whipple.

After each observation of the magnet it is removed and replaced by a torsion-plummet of equal weight, the position of which is observed when it has come to perfect rest a few hours after the observation.

Should any torsion be found to have been introduced into the thread, a suitable correction is applied to the observation.

Observations have been made at noon on two consecutive days in each month, the mean of which is inserted in the Table.

DIP.

In Table I. we have a record of the observed values of dip made with circle 33 Barrow, each observation being the mean of two made with each of the two needles belonging to that circle.

Table I.

Magnetic Dip as determined at the Kew Observatory.

	1869.	1870.	1871.	1872.	1873.	1874.	Mean of 6 years.
April	68° 2′·6	67° 57′·6	67° 59′·0	67° 53′·8	67° 53′·3	67° 50′·8	67° 56′·18
May	0·7	57·7	56·0	53·8	50·9	49·0	54·68
June	0·4	55·5	[67 56·0]	53·5	51·7	47·1	54·03
July	67 58·9	56·8	55·9	53·0	51·3	50·9	54·49
August ...	59·2	59·0	58·1	52·3	51·1	49·4	54·85
September	68 1·3	68 0·1	67 53·9	67 54·3	67 51·6	67 52·2	67 55·57
	68 0·52	67 57·78	67 56·48	67 53·45	67 51·65	67 49·90	67 54·96

	1869–70.	1870–71.	1871–72.	1872–73.	1873–74.	1874–75.	Mean of 6 years.
October ...	68° 0′·3	68° 1′·0	67° 56′·0	67° 54′·4	67° 52′·4	67° 49′·1	67° 55′·53
November	2·3	67 58·6	57·0	55·0	51·1	50·0	55·67
December	0·2	57·6	55·7	53·5	49·7	50·3	54·50
January ...	0·6	56·4	55·1	53·3	50·9	49·2	54·25
February	67 59·4	57·4	55·3	53·5	50·3	48·9	54·13
March ...	67 59·0	67 58·1	67 55·5	67 52·8	67 50·0	67 48·8	67 54·03
	68 0·30	67 58·18	67 55·77	67 53·75	67 50·73	67 49·38	67 54·68
	68 0·41	67 57·98	67 56·12	67 53·60	67 51·19	67 49·64	67 54·82

The number within brackets is interpolated.

The absolute values of the dip corresponding to the beginning of October in each of the years from 1868 to 1874 and the secular change in each year are as follows:—

	° ′	Sec. change. ′
From April 1868 to March 1869....	68 2·13	
„ 1869 „ 1870....	0·41	−1·72
„ 1870 „ 1871....	67 57·98	−2·43
„ 1871 „ 1872....	56·12	−1·86
„ 1872 „ 1873....	53·60	−2·52
„ 1873 „ 1874....	51·19	−2·41
„ 1874 „ 1875....	49·64	−1·55

Mean of the six years corresponding to middle epoch, April 1, 1872 .. } 67° 54′·82. Mean secular decrease .. } 2′·15.

The annual variation and semiannular inequality for the same period are as follows:—

Table II.

Date.	Corrections for secular change.	67° 54′·82 ± secular change.	Observed values.	Observed *minus* calculated.	
				April to September.	October to March.
July 1, 1869	+ 5′·91	68° 0′·73	68° 0′·52	− 0′·21	′
Jan. 1, 1870	+ 4·84	67 59·76	0·30	……	+ 0·64
July 1, 1870	+ 3·76	58·58	67 57·78	− 0·80	
Jan. 1, 1871	+ 2·69	57·51	58·18	……	+ 0·67
July 1, 1871	+ 1·61	56·43	56·48	+ 0·05	
Jan. 1, 1872	+ 0·54	55·36	55·77	……	+ 0·41
July 1, 1872	− 0·54	54·28	53·45	− 0·83	
Jan. 1, 1873	− 1·61	53·21	53·75	……	+ 0·54
July 1, 1873	− 2·69	52·13	51·65	− 0·48	
Jan. 1, 1874	− 3·76	51·06	50·73	……	− 0·33
July 1, 1874	− 4·84	49·98	49·90	− 0·08	
Jan. 1, 1875	− 5·91	48·91	49·38	……	+ 0·47
				− 0·39	+ 0·40

These six years show a semiannual inequality in the dip, the mean giving a lower reading by 0′·40 in the six months from April to September, and a higher by 0′·40 in the other six monthis, viz. October to March, than the average for the year.

This amount appears to be variable, the range in the six years ending March 1863 published by Sir E. Sabine being 1′·31, in the six years ending March 1869 discussed by Dr. Stewart but 0′·54, and in the six years now under consideration 0′·80.

The mean annular secular change as deduced from the three series of observations is as follows :—

Epoch.	Mean dip.	Difference.	Mean annual secular change.
April 1, 1860 ………	68° 20′·07		
April 1, 1866 ………	68 6·62	13′·45	2′·26
April 1, 1872 ………	67 54·82	11·80	1·97

Taking the mean secular change from the value for each year, we have

Series 1…………	2′·00
„ 2…………	1·92
„ 3…………	2·15

The probable error of a monthly determination of the dip as found by the method of least squares from the six years' observations, after the application to each observation of the correction for secular and semi-annual change, is ± 0′·78.

The error in series 1 was ± 0′·71, and in series 2 ± 0′·96.

HORIZONTAL FORCE.

The monthly values of the horizontal force, as observed by the Kew Unifilar, are given in Table III.

The method of reduction is the same as that used in the two former papers, described in the first.

Table III.

Monthly Values of the Horizontal Component of the Magnetic Force at Kew, computed from the Experiments of Deflection and Vibration with the Collimator Magnet KC 1.

	1869.	1870.	1871.	1872.	1873.	1874.	Mean of 6 years.
April	3·8499	3·8542	3·8599	3·8642	3·8762	3·8801	3·8641
May	3·8504	3·8502	3·8636	3·8723	3·8758	3·8857	3·8663
June	3·8546	3·8560	[3·8622]	3·8688	3·8773	3·8816	3·8668
July	3·8562	3·8619	3·8608	3·8704	3·8794	3·8812	3·8683
August ...	3·8495	3·8660	3·8623	3·8701	3·8785	3·8849	3·8685
September	3·8530	3·8552	3·8646	3·8746	3·8797	3·8768	3·8673
	3·8523	3·8572	3·8622	3·8701	3·8778	3·8817	3·8669

	1869–70.	1870–71.	1871–72.	1872–73.	1873–74.	1874–75.	Mean of 6 years.
October ...	3·8544	3·8519	3·8700	3·8731	3·8691	3·8843	3·8671
November	3·8567	3·8621	3·8647	3·8641	3·8746	3·8815	3·8673
December	3·8473	3·8575	3·8657	3·8735	3·8856	3·8810	3·8684
January ...	3·8576	3·8590	3·8682	3·8698	3·8768	3·8846	3·8693
February	3·8529	3·8634	3·8594	3·8747	3·8792	3·8882	3·8696
March ...	3·8783	3·8642	3·8672	3·8790	3·8803	3·8833	3·8754
	3·8579	3·8597	3·8659	3·8724	3·8776	3·8838	3·8695
	3·8551	8·8585	3·8640	3·8712	3·8777	3·8828	8·8682

The number within brackets is interpolated.

The absolute values of the horizontal force corresponding to the beginning of October in each of the years from 1869 to 1874 and the secular change in each year are as follows:—

Table IV.

		Secular change.
From April 1869 to March 1870........	3·8551	
„ 1870 „ 1871........	3·8585	+·0034
„ 1871 „ 1872........	3·8640	+·0055
„ 1872 „ 1873........	3·8712	+·0072
„ 1873 „ 1874........	3·8777	+·0065
„ 1874 „ 1875........	3·8828	+·0051

Mean of the six years corresponding to the middle epoch, April 1, 1872 } 3·8682. Mean secular change.... } +·0055.

In order to exhibit semiannual inequality in the horizontal force, Table V. has been formed in a similar manner to Table II.

Table V.

Date.	Correction for secular change.	3·8682 ± secular change.	Observed values.	Observed *minus* calculated.	
				April to September.	October to March.
July 1, 1869	− 0·0152	3·8530	3·8523	− ·0007	
Jan. 1, 1870	− 0·0125	3·8557	3·8579	......	+ ·0022
July 1, 1870	− 0·0097	3·8585	3·8572	− ·0013	
Jan. 1, 1871	− 0·0070	3·8612	3·8597	......	− ·0016
July 1, 1871	− 0·0042	3·8640	3·8622	− ·0018	
Jan. 1, 1872	− 0·0014	3·8668	3·8659	......	− ·0009
July 1, 1872	+ 0·0014	3·8696	3·8701	+ ·0005	
Jan. 1, 1873	+ 0·0042	3·8724	3·8724	......	·0000
July 1, 1873	+ 0·0070	3·8752	3·8778	+ ·0026	
Jan. 1, 1874	+ 0·0097	3·8779	3·8776	......	− ·0003
July 1, 1874	+ 0·0125	3·8807	3·8817	+ ·0010	
Jan. 1, 1875	+ 0·0152	3·8834	3·8838	......	+ ·0004
Mean difference between the observed and calculated values in the respective semiannual periods.........				·0000	·0000

Table IV. shows the mean annual secular change during the last six years to have been precisely the same as during the six years previous, and slightly greater than in the period 1857 to 1863, when it was ·0053.

Table V. also agrees with Table VII. in Dr. Stewart's discussion, in not exhibiting any trace of semiannnal inequality, thereby differing from Sir E. Sabine's paper, in which for the years 1857 to 1863 an inequality amounting to ·0026 was shown to exist.

The probable error of a monthly determination of the horizontal force as determined by least squares from the six years series, after the correction for secular change has been applied to each observation, is ±·0024.

TOTAL FORCE.

We find in Table III. that the means of the April to September values of the *horizontal* component of the force in the six years is 3·8669, corresponding in epoch to January 1, 1872, and in Table I. that the mean of the April to September values of the dip in the same six years is 67° 54′·96, corresponding to the same epoch.

We find also in Table III. that the means in the six years of all the October to March values are for the horizontal force 3·8695, and for the dip 67° 54′·68, corresponding to epoch July 1, 1872.

These values may be reduced to a common epoch by applying to the former dip the correction of −1′·07 as the proportional part of the secular change as determined by the whole six years' observations.

Correcting in a similar manner the horizontal force for the same period, we get:—

	Horiz. Force.	Dip.
From the April to September observations (reduced to epoch July 1, 1872)	3·86965	67° 53′·89
And from the October to March observations (reduced to the same epoch)	3·86950	67 54·68

We have then for the total force derived from the first series 3·86965 sec 67° 53′·89 = 10·28463 British units, and for the second series 3·86950 sec 67° 54′·68 = 10·29013, showing thus a difference of 0·00550 as the measure of the greater intensity of the terrestrial magnetic force in the October and March period than in the April to September period.

The amount determined from the first six years' observations by Sir E. Sabine was 0·00317; the second six years, 1863 to 1869, gave 0·00363.

ABSOLUTE DECLINATION.

The observations of declination made with the Kew Unifilar during the periods corresponding to those for which the force and dip observations were discussed have not been published, a much more elaborate series of observations being available in the records of the Kew self-recording Declinometer.

These were fully treated by Sir E. Sabine for the years 1857 to 1862 inclusive, in the Philosophical Transactions for 1863, page 290; and a paper carrying the investigation up to the end of 1873 is now in course of preparation.

We here give the results of the observations made monthly, in a form similar to that in which the force and dip observations are drawn up.

Table VI.

The Monthly observations of Absolute Declination at noon, observed with the Declinometer.

Month.	1869.	1870.	1871.	1872.	1873.	1874.	Mea six y
pril	20° 31′ 23″·3	20° 25′ 49″·2	20° 17′ 59″·0	20° 8′ 49″·4	20° 2′ 8″·0	19° 51′ 21″·1	20° 12
ay	20 33 35·8	20 32 17·2	20 16 43·3	20 3 21·9	19 53 19·1	19 53 38·8	20 12
ne	20 33 39·2	20 25 5·5	[20 16 48·8]	20 10 43·6	19 56 45·3	19 49 44·4	20 12
ly	20 34 39·8	20 25 45·7	20 16 54·4	20 10 11·7	20 1 43·4	19 49 35·0	20 13
gust ...	20 30 44·5	20 23 18·4	20 20 5·8	20 6 54·3	19 55 5·7	19 49 23·5	20 10
ptember	20 24 51·8	20 24 24·2	20 15 59·0	20 7 20·4	19 59 49·2	[19 49 29·8]	20 10
	20 31 29·07	20 26 6·72	20 17 24·72	20 7 53·55	19 58 8·45	19 50 32·05	20 11

Table VI. (*continued*).

th.	1869–70.	1870–71.	1871–72.	1872–73.	1873–74.	1874–75.	Mean o six year
r ...	20° 27′ 7″·0	20° 20′ 48″·0	20° 19′ 2″·4	20° 3′ 38″·4	19° 52′ 58″·7	19° 49′ 35″·4	20° 8′ 51″
ber.	20 31 48·5	20 15 25·3	20 9 48·8	20 4 30·2	19 49 44·5	19 46 7·9	20 6 14
ber .	20 22 28·0	20 17 26·2	20 7 5·2	20 1 31·4	19 54 0·4	19 41 19·2	20 3 58
y ...	20 24 28·9	20 17 29·0	20 7 49·1	20 2 25·1	19 54 8·0	19 47 54·5	20 5 42
y .	20 24 40·8	20 18 5·6	20 8 57·0	20 4 2·4	19 51 12·1	19 47 58·9	20 5 49
...	20 29 5·4	20 19 22·6	20 12 6·0	20 4 59·9	19 58 47·2	19 46 41·1	20 8 30
	20 26 36·43	20 18 6·12	20 10 48·08	20 3 31·23	19 53 28·48	19 46 36·17	20 6 31
	20 29 2·75	20 22 6·42	20 14 6·40	20 5 42·39	19 55 48·46	19 48 34·11	20 9 13

The absolute values of the Declination, corresponding to the beginning of October in each of the years comprehended in Table VI., and the secular change in each year are:—

		Secular change.
From April 1869 to March 1870	20° 29′ 2″·75	
„ 1870 „ 1871	22 6·42	−6′ 56″·33
„ 1871 „ 1872	14 6·40	−8 0·02
„ 1872 „ 1873	5 42·39	−8 24·01
„ 1873 „ 1874	19 55 48·46	−9 53·93
„ 1874 „ 1875	48 34·11	−7 14·35

Mean of the six years corresponding to the middle epoch, April 1, 1872...... } 20° 9′ 13″·42. Mean secular decrease... } −8′ 5″·72.

The semiannual inequality is exhibited in the following Table:—

Table VII.

Date.	Correction for secular change.	20° 9′ 13″·42 ± secular change.	Observed.	*Minus* calculated.	
				April to September.	October to March.
July 1, 1869	+ 22′ 15″·73	20° 31′ 29″·15	20° 31′ 29″·07	− 0′ 0″·08	
Jan. 1, 1870	+ 18 12·87	27 26·29	26 36·43	......	− 0′ 49″·86
July 1, 1870	+ 14 10·01	23 23·43	26 6·72	+ 2 43·29	
Jan. 1, 1871	+ 10 7·15	19 20·57	18 6·12	......	− 1 14·45
July 1, 1871	+ 6 4·29	15 17·71	17 24·72	+ 2 7·01	
Jan. 1, 1872	+ 2 1·43	11 14·85	10 48·08	......	− 0 26·77
July 1, 1872	− 2 1·43	7 11·99	7 53·55	+ 0 41·56	
Jan. 1, 1873	− 6 4·29	3 9·13	3 31·23	......	+ 0 22·10
July 1, 1873	− 10 7·15	19 59 6·27	19 58 8·45	− 0 57·82	
Jan. 1, 1874	− 14 10·01	55 3·41	53 28·48	......	− 1 34·93
July 1, 1874	− 18 12·87	51 0·55	50 32·05	− 0 28·50	
Jan. 1, 1875	− 22 15·73	46 57·69	46 36·17	......	− 0 21·52
Mean difference between the observed and calculated values in the respective semiannual periods......... }				+ 0 40·01	− 0 40·90

The mean annual secular change observed, 8′ 5″·72 declination diminishing, is larger than that determined by Sir E. Sabine, which was 7′ 39″; but this is only in accordance with the opinion expressed in the former paper, where it is shown that the secular change is a variable one, and is probably now becoming progressively more rapid.

The semiannual inequality is also largely increased, being now 81″·80, whereas between 1857 and 1862 it was only 58″·85; possibly part of this difference may, however, be due to the fact of the observations now under notice having only been made at isolated periods, whilst the latter result was obtained from the hourly readings of the magnetograph recording the declination continuously.

The observations discussed in this paper have been made and reduced by Mr. G. M. Whipple, B.Sc., Magnetic Assistant, and Messrs. Callum, Power, and Figg, observers, under his supervision.

III. "Contributions to the Minute Anatomy of the Thyroid Gland of the Dog." By E. Cresswell Baber, M.D. Lond. Communicated by Dr. Klein, F.R.S. Received December 9, 1875.

(Abstract.)

The minute structure of the thyroid gland generally, and of its lymphatics in particular, are subjects still but imperfectly understood. With the view of elucidating the latter, the following research was made on the thyroid gland of the dog. The research was carried out under the direction of Dr. Klein. On injecting the lymphatics of this organ with Berlin blue, by the method of puncture, they present the following characters:—

Traversing the gland, chiefly in a longitudinal direction, are large *lymphatic vessels* provided with valves. In direct connexion with these, and permeating the gland in all directions, is a dense meshwork of *lymphatic tubes* and *spaces*. The smaller lymphatic tubes run between individual gland-vesicles, the larger between groups of the same. They accommodate themselves accurately to the intervals left between the vesicles, and where the intervals are larger they expand into irregularly shaped lymphatic spaces. They present no appearance of terminating in blind extremities as stated by some authors. Injections with nitrate of silver show the lymphatic vessels, tubes, and spaces to be all lined with a continuous layer of endothelial plates.

During this investigation it became necessary to study more carefully the interalveolar tissues. This led to the discovery in them of a tissue which does not appear to have yet been described. This tissue, which is designated by the author by the name of "*parenchyma*," consists of large rounded cells, each provided with an oval nucleus, found either singly or in groups amongst the epithelial cells. From appearances presented by the parenchymatous cells, the author concludes that they originate external to the vesicles by exerting pressure on the epithelial wall of the vesicles; they then produce a flattening and absorption of the same, and finally make their way through it into the interior of the vesicle.

The author in conclusion points to the *morphological identity* existing between the contents of the lymphatics and those of the vesicles—the contents, namely, of both appear during life to be a viscid substance which, in sections of hardened specimens, present a like morphological aspect, and stain in a similar manner with reagents. This identity, if proven in other respects, will go far to show that one, possibly the chief, function of the thyroid gland is the formation in the vesicles of a material which is carried by the lymphatics into the general circulation.

This paper is accompanied by nineteen drawings illustrative of the lymphatics and parenchyma of the glands.

IV. "Research on the Minute Anatomy of the Alimentary Canal." By HERBERT WATNEY, M.A., Demonstrator of Microscopical Anatomy at St. George's Hospital. Communicated by Dr. KLEIN, F.R.S., Assistant Professor in the Brown Institution. Received December 16, 1875.

(Abstract.)

This research was commenced and carried on for the first fifteen months under the direction of Dr. Klein; during the last year it was continued independently.

Chapter I. describes the minute anatomy of the mucous membrane of the small intestine and the method of fat-absorption.

The author commences the Chapter by giving a history of the researches of previous observers, and the methods he employed for hardening and staining the tissue. He then gives a description of the minute structure of the mucosa.

The following are the results obtained.

1. The [epithelium.—Lymph-corpuscles are constantly found among the epithelial cells of the intestine. Further it is found that the epithelium contains a reticulum continuous with the reticulum of the mucosa; this reticulum appears in horizontal sections of the epithelium as small branched cells, which sometimes show a nucleus. In vertical sections the reticulum is seen as a dark line at the base of the epithelium, and from this dark line fine processes run among the epithelial cells. The reticulum is stained very deeply by chloride of gold or by hæmatoxylin.

In teased preparations, if the epithelial cells are isolated, shreds of the reticulum are seen to be attached to the separate cells.

The epithelial cells are described as being closed at their free extremities.

Groups of young cells are found. These groups ("epithelial buds") are due to germination.

2. The membrana propria covering the villi is composed of large cells. In vertical sections the cells are seen to be round or oval, and lie close below the above-mentioned dark line. When the membrane is separated from the rest of the tissue, it is seen to be composed of these cells arranged as an endothelium. The membrana has holes or gaps in it; and in teased preparations the superficial capillaries are always attached to it, as the large cells partially surround the vessels. Villi which are denuded of their epithelium are bordered by these large cells, and not by the dark line, as the reticulum (which forms the dark line) breaks off with the epithelial cells.

In oblique sections of the villi the reticulum is seen to surround the cells forming the membrana.

3. The membrana of Lieberkühn's crypts, when isolated from the surrounding structures and viewed from above, is found to be a homogeneous membrane with nuclei imbedded in it. In oblique sections of the membrane *in situ* it is seen to be composed of cells, and the reticulum is found to surround the cells composing it.

4. The muscle-endings in the mucosa.—In cross sections of the muscle-fibres of the muscularis mucosæ, a reticulum is seen to surround the individual muscle-fibres; this reticulum is continuous with that of the mucosa.

The author next describes the manner in which the muscle-fibres terminate in the rabbit's colon. The individual fibres are attached to the large cells forming the membrana propria by means of the reticulum.

This reticulum must therefore be regarded not only as a network of threads, but as forming in places membranous investments.

5. The muscle-fibres in the villi have an adventitia formed by the reticulum of the villus; if the muscle-fibres end near the membrana, the adventitia may be attached to the endothelial cells forming the membrane.

6. The blood-vessels are found to have an adventitia formed by the reticulum. In the veins the reticulum surrounds the endothelial cells and *even passes between them.* In the arteries the reticulum surrounds the muscle-fibres; and where the latter are few and scattered, the reticulum forms a very definite adventitia to the vessel.

7. The chyle-vessels are also found to have an adventitia formed by the reticulum; *i. e.* in longitudinal sections of the vessel threads are seen attaching the vessel to the reticulum. The reticulum can be seen to penetrate between the endothelial cells in the same manner as in the veins.

8. The tissue of the mucosa is shown to be composed everywhere of a reticulum and of cells held in its meshes. The author finds that while there is no difference, or only slight differences, between the reticulum

of the villus and that of the lymphatic follicles, there are considerable differences between the cells of a lymphatic follicle and those of the villi. In the villi the cells are polygonal, with oval nuclei and faintly granular protoplasm; the cells are arranged as an endothelium, and can hardly be distinguished from the endothelial cells of the membrana propria, of the blood-vessels, and of the lymphatics. A gradual transition is found from the spherical lymph-corpuscles of the lymphatic follicles to the polygonal cells (connective-tissue corpuscles) of the upper part of the villi.

It is found that there are more lymph-corpuscles in the villi of some animals than in those of others.

The author concludes that "the mucous membrane of the intestine is pervaded everywhere by a reticulum, similar to and continuous with that found in the lymphatic follicles of Peyer's patches. This reticulum is situated among all the other elements which are contained in its meshes. This is true of the epithelial cells, the muscle-fibres, the cells of the parenchyma, the endothelial plates of the membrana propria, of the blood-vessels, and of the lymphatics."

9. Fat-absorption by the reticulum—(*a*) *by the reticulum between the epithelial cells.*—The fat is seen to be arranged in lines between the individual cells on viewing the epithelium from above. The separate cells in teased preparations appear to contain fat; but it is considered that this appearance is due to the fat-particles in the attached threads of reticulum.

The paper then relates the different situations in which this reticulum has been seen (as in the salivary glands, rete Malpighii of the skin, serous membranes, epithelium of the respiratory tract, &c.), with the different views which various authors have held concerning it.

(*b*) *Fat-absorption by the reticulum of the villus.*—During absorption fat is found to travel by the reticulum.

Chapter II. gives an account of the minute anatomy of the pyloric end of the stomach. This chapter commences by a short history of previous researches, then follows a description of the minute structure. The following are the results obtained:—

1. The surface is seen to present somewhat parallel folds; the stomach-tubes opening on the summits of these folds are longer than those which open in the depressions between the folds.

2. The epithelium is described as being closed during inanition, but open at its free extremity during secretion.

3. The germination of the epithelium is next described. The conclusions arrived at are:—that the epithelial cells divide; that the small rounded cells (other than the lymph-corpuscles) are the products of their division; that these small cells, increasing in size, rise up among the older cells, push them to one side and become short broad cells; that the

short broad cells divide longitudinally, and form groups of two or three, or even more cells, which the author calls "epithelial buds."

4. A reticulum among the epithelial cells is described: it is found to be very delicate, and does not extend to the surface.

5. The membrana propria is found to be composed of large cells.

6. The muscle-endings in the plicæ villosæ are similar to those in the colon of the rabbit, already described.

7. Perivascular spaces are found in the upper part of the plicæ villosæ; these spaces are bordered by endothelial cells: the membrana propria forms the upper wall of the space.

8. The proper gland-tubes.—A fine reticulum is described as occurring among the epithelium of these glands. The nuclei are found usually as flattened disks lying at the base of the cells. The nuclei are, however, during digestion occasionally found to be spherical in form. A third kind of nucleus was also found, which was possibly intermediate between the two other forms.

Chapter III. describes the mucous membrane at the point of transition between the stomach and intestine: after giving a short history of the subject, it is shown that in many animals Brunner's glands are only the continuation of the proper glands of the stomach. Part of the proper gland-tubes break through the muscularis mucosæ, and then the glands are situated in the mucosa and submucosa; finally they are only found in the submucosa.

The mucosa at the point of transition was found to contain lymphoid follicles in very varying amount, the mucosa being in some animals almost free from them, and in others composed in a great measure of lymphatic tissue. This latter condition was found to be the case in dogs which were kept on a very reduced diet.

Presents received, January 6, 1876.

Transactions.

Batavia:—Bataviaasch Genootschap van Kunsten en Wetenschappen. Verhandelingen. Deel XXXVII., XXXVIII. roy. 8vo. 1875. Tijdschrift voor Indische Taal-, Land-, en Volkenkunde. Deel XXI. Afl. 5, 6; Deel XXII. Afl. 4–6; Deel. XXIII. Afl. 1. 8vo. 1874–75. Notulen van de Algemeene en Bestuurs-Vergaderingen. Deel XII. No. 4; Deel. XIII. No. 1, 2. 8vo. 1875.
The Society.

Copenhagen:—Académie Royale. Mémoires. Classe des Sciences. 5me Série. Vol. X. No. 7, 8, 9; Vol. XI. No. 1; Vol. XII. No. 1. 4to. 1875. Bulletin pour 1874. No. 3; 1875. No. 1 (Oversigt). 8vo.
The Academy.

Transactions (*continued*).

Frankfort-on-Main:—Senckenbergische Naturforschende Gesellschaft. Abhandlungen. Band IX. Heft 3, 4. 4to. *Frankfurt-a.-M.* 1874–75. Bericht, 1873–74. 8vo. 1875. The Society.

Liverpool:—Literary and Philosophical Society. Proceedings. No. 29. 8vo. 1875. The Society.

London:—Clinical Society. Transactions. Vol. VIII. 8vo. *London* 1875. The Society.

Institution of Naval Architects. Transactions. Vol. XVI. 4to. 1875. The Institution.

Statistical Society. Journal. Vol. XX. Part 2; XXII. Part 1, 3, 4; XXIII. to XXXVIII. Part 3. 8vo. 1857–75. General Index to Volumes XVI.–XXV., and to Volumes XXVI.–XXXV. 8vo. 1863–74. The Society.

Luxembourg:—Institut Royal Grand-Ducal. Publications. Section des Sciences Naturelles. Tome XV. 8vo. 1875. The Institute.

Plymouth:—Devonshire Association for the Advancement of Science, Literature, and Art. Report and Transactions. Vol. VII. 8vo. 1875. The Association.

Salem [U.S.]:—American Association for the Advancement of Science. Proceedings. Twenty-third Meeting, held at Hartford, Conn., August 1874. 8vo. 1875. The Association.

Upsala:—Regia Societas Scientiarum. Nova Acta. Ser. 3. Vol. IX. fasc. 2. 4to. 1875. The Society.

Observations, Reports, &c.

Dehra Dun:—Great Trigonometrical Survey of India. Synopsis of the Results of the Operations. Vol. V. Rahun Meridional Series, by Colonel J. T. Walker, F.R.S. 4to. 1875. The Viceroy of India.

Greenwich:—Royal Observatory. Astronomical and Magnetical and Meteorological Observations made in the year 1873, under the direction of Sir George B. Airy, K.C.B. 4to. *London* 1875. Results of Astronomical Observations. 4to. Results of Magnetical and Meteorological Observations. 4to. The Admiralty.

London:—Army Medical Department. Report for the year 1873. Vol. XV. 8vo. 1875. The Department.

Medical Department of the Navy. Statistical Report on the Health of the Navy for the year 1874. 8vo. 1875. The Department.

Upsala:—l'Observatoire de l'Université. Bulletin Météorologique Mensuel. Vol. VI. Année 1874. 4to. 1874–75. The Royal Society of Upsala.

Blacker (Rev. B. H.) Brief Sketches of the Parishes of Booterstown and Donnybrook, in the County of Dublin. Part 3. 12mo. *Dublin* 1872. The Author.

François de Chaumont (F. S. B.) Lectures on State Medicine delivered before the Society of Apothecaries. 8vo. *London* 1875. The Author.

Harrison (W. H.) Spirit People. 12mo. *London* 1875. The Author.

Hartley (W. N.) Air and its relations to Life. 8vo. *London* 1875. The Author.

Marey (—) Physiologie Expérimentale. Travaux du Laboratoire. Année 1875. 8vo. *Paris* 1866. The Author.

Strachan (R.) On the Weather of thirteen Autumns. 8vo. *London.* The Author.

Ure (Dr. Andrew), F.R.S. A Slight Sketch, reprinted from 'The Times' of January 1857. 12mo. *London* 1874. Mrs. Mackinlay.

January 20, 1876.

Transactions.

Bremen :—Naturwissenschaftlicher Verein. Abhandlungen. Band IV. Heft 2, 3. 8vo. 1875. Beilage. No. 4. 4to. 1874. The Institution.

Dresden :—Verein für Erdkunde. XII. Jahresbericht. Wissenschaftlicher Theil. 8vo. 1875. The Institution.

Edinburgh :—Scottish Meteorological Society. Journal. New Series. No. 43–46. 8vo. 1874–75. The Society.

Hamburg :—Naturwissenschaftlicher Verein. Abhandlungen aus dem Gebiete der Naturwissenschaften. Band V. Abth. 4; Band VI. Abth. 1. 4to. 1873. The Institution.

London :—Iron and Steel Institute. Journal. 1875. No. 1. 8vo. The Institute.

St. Bartholomew's Hospital. Reports, edited by J. Andrew and T. Smith. Vol. XI. 8vo. 1875. The Hospital.

Munich :—Königlich Bayerische Akademie der Wissenschaften. Abhandlungen der historischen Classe. Band XII. Abth. 3; Band XIII. Abth. 1. 4to. *München* 1875. Sitzungsberichte. Math.-phys. Classe. 1875. Heft 1, 2. 8vo. Philos.-philol. Classe. 1875. Band I. Heft 1–3; Band II. Heft 1, 2. 8vo. Ueber den religiösen Charakter des griechischen Mythos, von Dr. Conrad Bursian. 4to. 1875. Ueber die Beziehungen der Chemie zur Rechtspflege, von L. A. Buchner. 4to. 1875. Monographie der Sapindaceen-Gattung Serjania, von L. Radlkofer. 4to. 1875. Almanach. 1875. 12mo. The Academy.

Transactions (*continued*).

New York:—American Geographical Society. Journal. Vol. IV. 8vo. 1874. The Society.

Philadelphia:—American Philosophical Society. Transactions. New Series. Vol. XV. Part 2. 4to. 1875. Proceedings. Vol. XIV. No. 93. 8vo. 1874. The Society.

Reports &c.

Jefferson City:—Geological Survey of the State of Missouri. Report, including Field-Work of 1873–74. 8vo. 1874.
G. C. Broadhead, Esq., State Geologist.

Lisbon:—Observatorio do Infante D. Luiz. Annaes. Vol. XI. 1873. folio. *Lisboa.* The Observatory.

London:—The Admiralty. Report on Ocean-soundings and Temperatures, Pacific Ocean, H.M.S. 'Challenger.' No. 5. folio. 1875. Deep-sea Soundings and Temperatures, North-Atlantic Ocean, H.M.S. 'Valorous.' folio. 1875. The Admiralty.

Melbourne:—Observatory. Results of Observations in Meteorology, Terrestrial Magnetism, etc. taken during the year 1873. Vol. II. 8vo. Monthly Record of Results. Nov., Dec. 1874; Jan. to May 1875. 8vo. The Observatory.

Sydney:—Observatory. Results of Meteorological Observations made in New South Wales during 1873, under the direction of H. C. Russell. 8vo. 1875. The Observatory.

Washington:—Smithsonian Institution. Annual Report of the Board of Regents for the year 1873. 8vo. 1874. The Institution.

United-States Geological Survey of the Territories. Report by F. V. Hayden. Vol. VI. 4to. 1874. Lists of Elevations. Third Edition. 8vo. 1875. Catalogue of Publications. 8vo. 1874.
The Survey.

Ball (R. S.), F.R.S. The Theory of Screws: a Study in the Dynamics of a Rigid Body. 8vo. *Dublin* 1876. The Author.

Boileau (General J. T.), F.R.S. A new and complete set of Traverse Tables. New Edition. 8vo. *London* 1875. The Author.

Chantre (E.) Les Faunes Mammalogiques tertiaire et quaternaire du bassin du Rhône. 8vo. *Lyon* 1874. The Author.

—— et Lortet. Études Paléontologiques dans le bassin du Rhône, période quaternaire. folio. *Lyon* 1873–75. Mons. Chantre.

Chevreul (E.), For. Mem. R.S. D'une erreur de Raisonnement très-fréquente dans les Sciences. 4to. *Paris* 1871. Études des procédés de l'Esprit Humain dans la recherche de l'Inconnu. 4to. 1874. L'Enseignement devant l'Étude de la Vision. 4to. 1875. Explication de nombreux phénomènes qui sont une conséquence de la vieillesse. 4to. 1875. The Author.

Giedroyc (Prince Romuald) Résumé de l'Histoire du Portugal au xix^e siècle. 8vo. *Paris* 1875. The Author.

Merk (Conrad) Excavations at the Kesslerloch, near Thayngen, Switzerland, a Cave of the Reindeer period, translated by J. E. Lee. 8vo. *London* 1876. The Translator.

Pickering (C.) The Geographical Distribution of Animals and Plants (United-States Exploring Expedition. Vol. XV.). 4to. *Boston* (*U.S.*) 1854. The Author.

Plantamour (E.) et A. Hirsch. Détermination Télégraphique de la Différence de Longitude entre la Station Astronomique du Simplon et les Observatoires de Milan et de Neuchâtel. 4to. *Genève* 1875. The Author.

Shanks (W.) Papers from the Proceedings of the Royal Society on Constants and Primes, with MS. additions. 8vo. *London* 1867–75. The Author.

Silliman (B.) American Contributions to Chemistry. An Address, August 1, 1874. 8vo. *Philadelphia* 1874. The Author.

Spiller (P.) Die Urkraft des Weltalls nach ihrem Wesen und Wirken auf allen Naturgebieten. 8vo. *Berlin* 1876. The Author.

January 27, 1876.

Transactions.

Berlin:—Physikalische Gesellschaft. Die Fortschritte der Physik im Jahre 1870. Jahrgang XXVI. 8vo. 1874–75; Jahrg. XXVII. 1871. Abth. 1. 8vo. 1875. The Society.

Lund:—Universitet. Ars-Skrift. 1871 (Theologi, Mathematik, Philosophi); 1872 (Math., Philos.); 1873 (Math., Philos.). 4to. 1871–74. The University.

Melbourne:—Royal Society of Victoria. Transactions and Proceedings. Vol. XI. 8vo. 1874. The Society.

Milan:—Accademia Fisio-Medico-Statistica. Atti. Anno 31. 8vo. 1875. The Academy.

Newcastle-upon-Tyne:—Natural-History Transactions of Northumberland and Durham. Vol. V. Part 2. 8vo. 1875. The Tyneside Naturalists' Field-Club.

Philadelphia:—Franklin Institute. Journal. Vol. XCIX. No. 5, 6; Vol. C. No. 1–6. 8vo. 1875. The Institute.

St. Louis:—Academy of Science. Transactions. Vol. III. No. 2. 8vo. 1875. The Academy.

Transactions (*continued*).

Sydney:—Royal Society of New South Wales. Transactions for the year 1874. 8vo. 1875. The Society.

Warwick:—Warwickshire Natural-History and Archæological Society. Thirty-ninth Annual Report. 8vo. 1875. The Society.

Reports &c.

London:—Board of Trade. Ninth Annual Report of the Warden of the Standards on the Standard Weights and Measures Department of the Board of Trade for 1874-75. 8vo. *London* 1875. The Warden.

British Museum. Catalogue of Additions to the Manuscripts in the years 1854-60. 8vo. 1875. Catalogue of the Manuscripts in the Spanish Language, by Pascual de Gayangos. Vol. I. 8vo. 1875. Catalogue of the Birds. Vol. II. 8vo. 1875. The Trustees.

Paris:—Bureau des Longitudes. Annuaire pour l'An 1876. 12mo. *Paris.* The Bureau.

L'Observatoire de Montsouris. Annuaire Météorologique et Agricole pour l'An 1876. 12mo. *Paris.* The Observatory.

Journals.

American Journal of Science and Arts. Third Series. Vol. X. No. 55-61. 8vo. 1875-76. The Editors.

New York Medical Journal. Vol. XXI. No. 6; Vol. XXII. No. 1-5. 8vo. 1875. The Editor.

Revue des Cours Scientifiques de la France et de l'Étranger. 6^e Année. No. 5, 47. 4to. *Paris* 1869. Revue Scientifique. 1^e Année. No. 7, 13; 2^e Année. No. 14; 3^e Année. No. 7; 4^e Année. No. 36, 47. 4to. 1871-75. The Editor.

Zeitschrift für die gesammten Naturwissenschaften, redigirt von C. G. Giebel. Neue Folge. 1875. Band XI. 8vo. *Berlin* 1875. The Editor.

Brunton (T. L.), F.R.S. Experimental Investigation of the Action of Medicines. 8vo. *London* 1875. On one of the Causes of Death during the Extraction of Teeth under Chloroform. 8vo. 1875. Atropia as an Antidote to Poisonous Mushrooms. 8vo. 1874. The Author.

Coues (E.) Abstract of Results of a Study of the Genera *Geomys* and *Thomomys*. 4to. *Washington* 1875. The U.S. Department of the Interior.

Hirn (G. A.) Exposition analytique et expérimentale de la Théorie Mécanique de la Chaleur. 3ᵉ Edition. Tome II. 8vo. *Paris* 1876. Sur l'Étude des moteurs thermiques et sur quelques points de la théorie de la Chaleur en général. 4to. 1876. The Author.

Jones (T. Wharton), F.R.S. Evolution of the Human Race from Apes and lower Animals a doctrine unsanctioned by Science. 8vo. *London* 1876. The Author.

Oil-Painting of the Hon. Robert Boyle, by Kneller, in gilt frame. Oil-Painting of Sir Charles Wheatstone, by Charles Martin, in gilt frame.

Thirteen Engraved Portraits of Francis Baily, Dr. Wm. Buckland, Sir Henry De la Beche, Faraday, Sir John Franklin, Thomas Graham, Sir Henry Holland, Moll, Sir Roderick Murchison, Sir James Ross, Canon Sedgwick (framed and glazed).

Six Photographic Portraits of Amici, Liebig, Priestley, &c. (framed and glazed).

The Bequest of the late Sir Charles Wheatstone, F.R.S.

February 3, 1876.

WILLIAM SPOTTISWOODE, M.A., Treasurer and Vice-President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On Formulæ of Verification in the Partition of Numbers."

By J. W. L. GLAISHER, M.A., F.R.S. Received December 18, 1875.

In writing down all the partitions of a number it is convenient to have tests which will verify that none have been omitted; and it is the main object of this paper to give formulæ which are available for this purpose.

At the Edinburgh Meeting of the British Association (Report 1871, Transactions of the Sections, p. 23), Sylvester communicated the elegant and useful test-formula

$$\text{I.} \qquad \Sigma(1-x+xy-xyz+\ \&\text{c.})=0,$$

where in any partition x denotes the number of 1's present, y the number of 2's, z the number of 3's, and the Σ extends to all the partitions of the given number n; so that $\Sigma 1 = N$, the total number of the partitions of n. A single formula of verification, however, is rarely sufficient to afford a perfect test of accuracy, as the effects produced by certain omissions may cancel one another. In the present case, for example, as the terms are alternately positive and negative, if the omitted partition contained one 1 and no 2 it would appear as 1 in the first term and as 1 in the second term, and its omission would thus not be pointed out. Having had occasion several times to employ Sylvester's equation I., and having found the need of some additional formula to be used in connexion with it, I was led to seek for identities which would afford similar verifications. It seemed natural first to investigate what I. became when all the signs were positive.

Starting from the identity

$$1+\frac{t}{1-t}+\frac{t^3}{1-t\,.\,1-t^2}+\frac{t^6}{1-t\,.\,1-t^2\,.\,1-t^3}+\&\text{c.}=1+t\,.\,1+t^2\,.\,1+t^3\ldots,$$

and dividing throughout by $1-t\,.\,1-t^2\,.\,1-t^3\ldots$ we have

$$\frac{1}{1-t.1-t^2.1-t^3\ldots.}+\frac{t}{(1-t)^2\,1-t^2.1-t^3\ldots}+\frac{t^3}{(1-t)^2(1-t^2)^2\,1-t^3\ldots}$$
$$+\&\text{c.}$$
$$=\frac{1+t.1+t^2.1+t^3\ldots}{1-t.1-t^2.1-t^3\ldots}$$
$$=(1+2t+2t^2+\&\text{c.})\,(1+2t^2+2t^4+\&\text{c.})\,(1+2t^3+2t^6+\&\text{c.})\ldots;$$

whence, equating the coefficients of t^n,

II. $$\Sigma(1+x+xy+xyz+\&\text{c.})=\Sigma 2^r,$$

where r is the number of different elements contained in a partition. Take as an example $n=9$; the partitions are:—

9

8+1
7+2
6+3
5+4

7+1+1
6+2+1
5+3+1
5+2+2
4+4+1
4+3+2
3+3+3

6+1+1+1
5+2+1+1
4+3+1+1
4+2+2+1
3+3+2+1
3+2+2+2

5+1+1+1+1
4+2+1+1+1
3+3+1+1+1
3+2+2+1+1
2+2+2+2+1

4+1+1+1+1+1
3+2+1+1+1+1
2+2+2+1+1+1

3+1+1+1+1+1+1
2+2+1+1+1+1+1
2+1+1+1+1+1+1+1

1+1+1+1+1+1+1+1+1

Here N (the number of partitions) $=30$, Σx (the number of 1's) $=67$, $\Sigma xy=47$, and $\Sigma xyz=10$. Also the number of partitions involving only one element $=3$, the number involving two elements $=17$, and the number involving three $=10$; and I. and II. become

$$30-67+47-10=0,$$
$$30+67+47+10=3\,.\,2+17\,.\,2^2+10\,.\,2^3.$$

Combining the formulæ I. and II., we have

$$\Sigma(1+xy+xyzw+\&c.)=\Sigma(x+xyz+\&c.)=\tfrac{1}{2}\Sigma 2^r=\Sigma 2^{r-1},$$

where $\Sigma 2^{r-1}$ may be written $\Sigma 2$, s denoting the number of *changes* in a partition. The two formulæ taken together, as just written, form of course a much better verification than either singly.

There are two subsidiary verifications connected with I. and II. which are also worth attention. From Jacobi's equation ('Fundamenta Nova,' p. 185),

$$\frac{1-t\,.\,1-t^2\,.\,1-t^3\ldots}{1+t\,.\,1+t^2\,.\,1+t^3\ldots}=1-2t+2t^4-2t^9+2t^{16}-\&c.,$$

we see that

III. $$\Sigma\pm 2^{r-1}=1,\ -1,\text{ or }0,$$

according as n is an even square, an uneven square, or not a square. The sign $+$ is to be taken if the partition contains an even number of terms, and the sign $-$ if the number is uneven.

Also from the same identity inverted, viz. from

$$\frac{1+t\,.\,1+t^2\,.\,1+t^3\ldots}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}=\frac{1}{1-2t+2t^4-2t^9+2t^{16}-\&c.},$$

we see that

IV. $$\Sigma 2^r=(-)^n(\text{R}-\text{R}'),$$

where $\text{R}=$ the number of representations of n as the sum of an even number of squares, and R′ the number of representations as an uneven number of squares.

In the case of $n=9$, of the three partitions involving only one element, all consist of an uneven number of terms; of the seventeen partitions involving two elements, in nine the number of terms is even, and in eight uneven; and of the ten partitions involving three elements, in five the number is even and in five uneven; so that since 9 is an uneven square, III. gives

$$\tfrac{1}{2}(-3\,.\,2+9\,.\,2^2-8\,.\,2^2+5\,.\,2^3-5\,.\,2^3)=-1.$$

The partitions of 9 into squares are four in number, viz. 9, 4+4+1, 4+1+1+1+1+1, 1+1+1+1+1+1+1+1+1; and these give rise respectively to $2, 3\,.\,2^3, 6\,.\,2^6, 2^9$ representations; so that substituting in IV.

$$30+67+47+10=(-)^9(384-2-24-512).$$

The following are also formulæ of verification:—

V. $$\Sigma(x-2xy+3xyz-\&c.)=\psi n,$$

where ψn denotes, as also in VI. and VII., the number of divisors of n, unity and n included. This formula does not verify the value of N, but it verifies Σx, Σxy, &c.; for $n=9$, $\psi n=3$; and it gives

$$67-2\,.\,47+3\,.\,10=3.$$

VI. $$\Sigma(1-2y+3yz-4yzw+\&c.)=\psi(n+1)-\psi n.$$

For $n=9$ (Σy, the total number of 2's) $=26$, $\Sigma yz=9$, $\Sigma yzw=1$, and

$$30-2\,.\,26+3\,.\,9-4\,.\,1=4-3.$$

VII. $$\Sigma\big(1-2[y]_1+3[yz]_2-4[yzw]_3+\&c.\big)=\psi(n+2)-1,$$

where $[\;]_r$ denotes that the enclosed quantity is zero for every partition which does not contain at least r 1's.

For $n=9$, $\Sigma[y]_1=19$, $\Sigma[yz]_2=3$, and

$$30-2\,.\,19+3\,.\,3=2-1.$$

VIII. $$\mathrm{N}-1=\Sigma(x-1-x-2\,.\,y+x-3\,.\,yz-\&c.),$$

where, as throughout, the point is written in place of brackets (ex. gr. $x-2\,.\,y$ stands for $(x-2)y$), and a negative factor is to be treated as zero.

For $n=9$, $\Sigma(x-1)=45$, $\Sigma(x-2\,.\,y)=17$, $\Sigma(x-3\,.\,yz)=1$, and

$$30-1=45-17+1.$$

IX. $$\mathrm{N}-n=\Sigma(\{x-3\}_2+\{x-5\}_3+\{x-7\}_4+\&c.),$$

where $\{\;\}_r$ denotes that the enclosed quantity is zero for every partition in which an element $>r$ appears.

For $n=9$, $\Sigma\{x-3\}_2=2+4+6=12$, $\Sigma\{x-5\}_3=1+2+4=7$, $\Sigma\{x-7\}_4=2$; and the formula gives

$$30-9=12+7+2.$$

X. $$\mathrm{N}-n=\Sigma\big(\{x-1\,.\,y\}_2+\{x-3\,.\,yz\}_3+\{x-6\,.\,yzw\}_4+\&c.,$$

where $\{\;\}_r$ has the same meaning as in IX., and 1, 3, 6.... are the triangular numbers.

For $n=9$, the formula gives

$$30-9=20+1.$$

XI. If n be uneven, $\Sigma\big(1-[x+1]^1-[x+1\,.\,y+1\,.\,z+1]^3-\&c.\big)=0$;

and if n be even, $\Sigma\big(1-[1]^0-[x+1\,.\,y+1]^2-[x+1\ldots w+1]^4-\&c.\big)=0$,

where $x=$ the number of 2's, $y=$ the number of 4's &c. in any partition, and $[\;]^r$ denotes that the enclosed quantity is equal to zero unless the partition contains exactly r ones, and no other uneven element. Thus $\Sigma[1]^0$ is equal to the number of partitions formed wholly of even elements. (x, y, z... may, of course, have zero values.)

For $n=9$, the first formula gives

$$30-12-10-5-2-1=0.$$

XII. $$\Sigma_1 2^r=\nu+P_2^1+P_{2,4}^{1,3}+P_{2,4,6}^{1,3,5}+\&c.,$$

where Σ_1 refers only to partitions in which all the elements are uneven, ν denotes the number of partitions of n into uneven elements (so that $\Sigma_1 1=\nu$); and, for example, $P_{2,4,6}^{1,3,5}$ denotes the number of partitions of n into the elements 2, 4, 6, 1, 3, 5, 7 .... (2, 4, 6 being the only admissible even elements, but all uneven elements being admissible), and in which 1, 3, 5 must each occur at least once; so that in the partitions all the uneven numbers and the (even) suffixes may appear, and the (uneven) exponents *must* all appear. (Thus we might have written $P_{2,4,6}^9$, &c. for $P_{2,4,6}^{1,3,5}$, &c.)

For $n=9$, we have

$$30=8+14+7+1.$$

The notation being as in XII.,

XIII. $$0=\nu-P_2^1+P_{2,4}^{1,3}-P_{2,4,6}^{1,3,5}+\&c.$$

For $n=9$, $$0=8-14+7-1.$$

Combining XII. with XIII., we have

$$\nu+P_{2,4}^{1,3}+P_{2,4,6,8}^{1,3,5,7}+\&c.=P_2^1+P_{2,4,6}^{1,3,5}+\&c.=\tfrac{1}{2}\Sigma 2^r.$$

XIV. $$P-P^2+P^{2,4}-P^{2,4,6}+\&c.=1 \text{ or } 0,$$

according as n is or is not a triangular number.

Here the notation is practically the same as in XII. and XIII.; P denotes the number of partitions into uneven elements, P^2 the number of partitions into the elements 2, 1, 3, 5 ..., in which 2 must appear, $P^{2,4}$ into the elements 2, 4, 1, 3, 5 ..., in which 2 and 4 must both appear, and so on.

For $n=9$, the formula gives

$$8-11+3=0.$$

The formulæ V. to XIV., which have just been written down, are merely translations into analytical language of the identities:—

$$\text{(V.)}\ \frac{t}{1-t}+\frac{t^2}{1-t^2}+\frac{t^3}{1-t^3}+\&c.=\frac{t}{(1-t)^2.1-t^2.1-t^3\ldots}$$
$$-\frac{2t^3}{(1-t)^2(1-t^2)^2.1-t^3\ldots}+\frac{3t^6}{(1-t)^2(1-t^2)^2(1-t^3)^2\ldots}-\&c.$$

$$\text{(VI.)}\ \left(\frac{1}{t}-1\right)\left(\frac{t}{1-t}+\frac{t^2}{1-t^2}+\&c.\right)=\frac{1}{1-t.1-t^2.1-t^3\ldots}$$
$$-\frac{2t^2}{1-t.(1-t^2)^2.1-t^3}+\&c.$$

$$\text{(VII.)}\ \frac{1}{1-t^2}+\frac{t}{1-t^3}+\frac{t^2}{1-t^4}+\&c.=\frac{1}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}$$
$$-\frac{2t^3}{1-t\,.\,(1-t^2)^2\,.\,1-t^3\ldots}+\frac{3t^6\,.\,t}{1-t\,.\,(1-t^2)^2(1-t^3)^2\ldots}-\&c.$$

$$\text{(VIII.)}\ \frac{1}{1-t}=\frac{1}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}-\frac{t^2}{(1-t)^2\,.\,1-t^2\,.\,1-t^3\ldots}$$
$$+\frac{t^5}{(1-t)^2(1-t^2)^2 1-t^3\ldots}-\&c.$$

$$\text{(IX.)}\ \frac{1}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}=\frac{1}{1-t}+\frac{t^2}{(1-t)^2}+\frac{t^4}{(1-t)^2\,.\,1-t^2}$$
$$+\frac{t^6}{(1-t)^3\,.\,1-t^2\,.\,1-t^3}+\&c.$$

$$\text{(X.)}\ \frac{1}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}=1+\frac{t}{(1-t)^2}+\frac{t^4}{(1-t)^2(1-t^2)^2}$$
$$+\frac{t^9}{(1-t)^2(1-t^2)^2(1-t^3)^2}+\&c.$$

$$\text{(XI.)}\ \frac{1}{1-t\,.\,1-t^2\,.\,1-t^3\ldots}=\frac{1}{1-t^2\,.\,1-t^4\,.\,1-t^6\ldots}$$
$$+\frac{t}{(1-t^2)^2\,.\,1-t^4\,.\,1-t^6\ldots}+\frac{t^2}{(1-t^2)^2(1-t^4)^2\,.\,1-t^6\ldots}+\&c.$$

$$\text{(XII.)}\ \frac{1+t\,.\,1+t^3\,.\,1+t^5\ldots}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}=\frac{1}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}$$
$$+\frac{t}{(1-t^2)\,.\,1-t\,.\,1-t^3\ldots}+\frac{t^4}{(1-t^2)(1-t^4)\,.\,1-t\ldots}+\&c.$$

$$\text{(XIII.)}\qquad 1\qquad=\frac{1}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}-\frac{t}{(1-t^2)\,.\,1-t\,.\,1-t^3\ldots}$$
$$+\frac{t^4}{(1-t^2)(1-t^4)\,.\,1-t\ldots}-\&c.$$

$$\text{(XIV.)}\ 1+t+t^3+t^6+t^{10}+\&c.=\frac{1}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}$$
$$-\frac{t^2}{(1-t^2)\,.\,1-t\,.\,1-t^3\ldots}+\frac{t^6}{(1-t^2)(1-t^4)\,.\,1-t\ldots}-\&c.;$$

all of which can be deduced without difficulty from the identities,

$$(\alpha)\ 1+tu\,.\,1+t^2u\,.\,1+t^3u\ldots=1+\frac{tu}{1-t}+\frac{t^3u^2}{1-t\,.\,1-t^2}$$
$$+\frac{t^6u^3}{1-t\,.\,1-t^2\,.\,1-t^3}+\&c.$$

$$(\beta)\ \frac{1}{1-tu\,.\,1-t^2u\,.\,1-t^3u\ldots}=1+\frac{tu}{1-t}+\frac{t^2u^2}{1-t\,.\,1-t^2}$$
$$+\frac{t^3u^3}{1-t\,.\,1-t^2\,.\,1-t^3}+\&c.$$

$$(\gamma)\ \frac{1}{1-tu\,.\,1-t^2u\,.\,1-t^3u\ldots}=1+\frac{t}{1-t}\,.\,\frac{u}{1-tu}+\frac{t^4}{1-t\,.\,1-t^2}\,.\,\frac{u^2}{1-tu\,.\,1-t^2u}+\frac{t^9}{1-t\,.\,1-t^2\,.\,1-t^3}\,.\,\frac{u^3}{1-tu\,.\,1-t^2u\,.\,1-t^3u}+\&c.$$

$$(\delta)\ \frac{1-t^2\,.\,1-t^4\,.\,1-t^6\ldots}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}=1+t+t^3+t^6+t^{10}+\&c.;$$

of which (α) and (β) are Euler's well known formulæ, and (γ) and (δ) are given by Jacobi ('Fundamenta Nova,' pp. 180, 185).

Of the fourteen verification formulæ the first two are generally most convenient; and, taken in connexion with III. and IV., the four equations form an interesting system of mutually related verifications. All the formulæ can be used with great facility after a little practice, but some are evidently far preferable to others. Nos. II., III. and IV. were communicated to the Bristol Meeting of the British Association (1875).

The following formulæ, XV. to XX., involve the consideration of the partitions of a number in which repetitions are excluded. If by Q (a, b, $c\ldots$) n be denoted the number of partitions without repetitions of n into the elements a, b, $c\ldots$, and by P (a, b, $c\ldots$) n the number of partitions into the same elements with repetitions, then, from the identity

$$2\,.\,1+t\,.\,1+t^2\,.\,1+t^3\ldots=1+\frac{1}{1-t}+\frac{t}{1-t\,.\,1-t^2}+\frac{t^3}{1-t\,.\,1-t^2\,.\,1-t^3}+\&c.,$$

which is derivable at once from (a), we have

$$\text{XV.}\quad 2Q(1,2,3\ldots)n=1+P^{1}(1,2)n+P^{1,2}(1,2,3)n+P^{1,2,3}(1,2,3,4)n+\&c.,$$

where $P^{1,2\ldots r}(1,2\ldots r+1)n$ denotes the number of partitions of n into the elements $1,2\ldots r+1$, in which all except the highest must appear at least once.

For $n=9$, $Q(1,2,3\ldots)n=8$, and the formula gives

$$2\,.\,8=1+5+7+3.$$

From the identity

$$\frac{1}{1+t\,.\,1+t^2\,.\,1+t^3\ldots}=1-t\,.\,1-t^3\,.\,1-t^5\ldots,$$

we have

$$\text{XVI.}\qquad P^{\text{even}}n-P^{\text{uneven}}n=(-)^nQ(1,3,5\ldots)n,$$

where $P^{\text{even}}n$ denotes the number of partitions of n that contain an even number of terms, and $P^{\text{uneven}}n$ the number that contain an uneven number. If n be even, all the partitions in $Q(1, 3, 5\ldots)n$ are included in $P^{\text{even}}n$; and if n be uneven, all are included in $P^{\text{uneven}}n$; so that we have the theorem that if all the partitions of n into uneven elements without repetitions be left out of consideration, then of the rest the number of partitions in which the number of terms is even is equal to the number of partitions in which the number of terms is uneven. For the case $n=9$, the partitions which contain only uneven elements without repetitions are two in number, viz. 9 and $1+3+5$; and of the rest, fourteen consist of an even, and fourteen of an uneven number of terms.

We have, as above,

$$(\epsilon)\ \frac{1}{1-t\,.\,1-t^3\,.\,1-t^5\ldots}=1+t\,.\,1+t^2\,.\,1+t^3\ldots$$
$$=1+t+t^2(1+t)+t^3(1+t)(1+t^2)$$
$$+t^4(1+t)(1+t^2)(1+t^3)+\&c.;$$

whence

$$\frac{1}{1-t^3\,.\,1-t^5\,.\,1-t^7\ldots}=1+t^{2+1}+t^{3+2}(1+t)+t^{4+3}(1+t)(1+t^2)+\&c.,$$

and we obtain

XVII. $P(3,5,7\ldots)n=$number of partitions without repetitions into the elements $1,2,3\ldots$, in which the two greatest parts are consecutive (*i. e.* differ by unity).

And also, by multiplying (ϵ) by $1-t$, we find that each side of XVII. $=Q(3,5,6,7,9\ldots)n$; so that if all the partitions without repetitions of a number n be written down, then

XVIII. the number of partitions not involving $1,2,4,8,16\ldots=$ the number of partitions in which the two greatest parts are consecutive.

In the case of $n=9$, XVII. gives $2=2$; and XVIII. of course also gives $2=2$, there being only two partitions without repetitions in which $1,2\ldots$ are not involved, viz. 9 and $6+3$, and two in which the two greatest parts are consecutive, viz. $4+3+2$ and $5+4$.

Euler's identity,

$$1-t\,.\,1-t^2\,.\,1-t^3\ldots=1-t-t^2+t^5+t^7-t^{12}-\&c.$$

(where the exponents are the pentagonal numbers), gives the theorem that

$$\text{XIX.}\qquad Q^{\text{even}}n-Q^{\text{uneven}}n=(-1)^m \text{ or } 0,$$

according as n is or is not of the form $\frac{1}{2}(3m^2\pm m)$. Thus we see that, considering only partitions without repetitions, the number of the partitions of a non-pentagonal number into an even number of parts is always equal to the number of its partitions into an uneven number; and that if the number be pentagonal the numbers of even and uneven partitionments differ only by unity. If $n=9$, $Q^{\text{even}}n=Q^{\text{uneven}}n=4$.

We deduce from (δ) that

$$1+t\,.\,1+t^3\,.\,1+t^5\ldots\{1-t^4\,.\,1-t^8\,.\,1-t^{12}\ldots\}=1+t+t^3+t^6+t^{10}+\&c.;$$

and by Euler's identity, just quoted, the quantity in { }

$$=1-t^4-t^8+t^{20}+t^{28}-t^{48}-\&c.;$$

whence

$$\text{XX.}\quad Q(1,3,5\ldots)n-Q(1,3,5\ldots)(n-4)-Q(1,3,5\ldots)(n-8)$$
$$+Q(1,3,5\ldots)(n-20)+\&c.=1 \text{ or } 0,$$

according as n is or is not a triangular number. The general term on the left-hand side is $(-)^m Q(1, 3, 5 \ldots)(n-6m^2 \pm 2m)$. For $n=9$, the formula gives

$$2-1-1=0.$$

There is a proposition of Euler's which follows immediately from (e), viz. that the number of partitions of a number into the uneven elements $1, 3, 5 \ldots$ is equal to the number of partitions without repetitions into the elements $1, 2, 3 \ldots$, or, in the notation already used, that $P(1, 3, 5 \ldots)n = Q(1, 2, 3 \ldots)n$. It is natural to suppose that this striking theorem should admit of a simple demonstration by converting the partitions of the one system into those of the other according to some rule, such as in Mr. Ferrers's method of showing the identity of the numbers of partitionments into the elements $1, 2, 3 \ldots m$, and into parts not exceeding m in number (Phil. Mag. S. 4. vol. v. p. 201, 1853). The conversion, though not so simple as that just referred to, is nevertheless elegant and elementary; it in effect consists of a transformation into the binary scale. Thus consider a partition into uneven numbers containing α 1's, β 3's, γ 5's, &c. This is transformable at once into $1 . \alpha + 3 . \beta + 5 . \gamma + \&c.$ Now express $\alpha, \beta, \gamma \ldots$ in the binary scale so that $\alpha = 2^a + 2^{a'} + \&c.$, $\beta = 2^b + 2^{b'} + \&c.$, $\gamma = 2^c + 2^{c'} + \&c.$, then the partition becomes $1(2^a + \&c.) + 3(2^b + \&c.) + 5(2^c + \&c.) + \&c.$, viz. becomes $2^a + 2^{a'} + \&c. + 3 . 2^b + 3 . 2^{b'} + \&c. + 5 . 2^c + 5 . 2^{c'} + \&c.$, in which no two parts are identical, since a number can be expressed in only one way in the form $2^m A$, A being uneven.

To illustrate this take Euler's example of $n=10$; the partitions into uneven elements are

(i) $9+1$,
(ii) $7+3$,
(iii) $7+1+1+1$,
(iv) $5+5$,
(v) $5+1+1+1+1+1$,
(vi) $5+3+1+1$,
(vii) $3+3+3+1$,
(viii) $3+3+1+1+1+1$,
(ix) $3+1+1+1+1+1+1+1$,
(x) $1+1+1+1+1+1+1+1+1+1$.

By the conversion (i) and (ii) remain unaltered; (iii) $=7+1 . 3=7+1(2+1)=7+2+1$; (iv) $=5 . 2=10$; (v) $=5+1 . 5=5+1(2^2+1$ $=5+4+1$; (vi) $=5+3+1 . 2=5+3+2$; (vii) $=3 . 3+1=3(2+1$ $+1=6+3+1$; (viii) $=3 . 2+1 . 4=6+4$; (ix) $=3+1 . 7=3+1(2$ $+2+1)=3+4+2+1$; (x) $=1 . 10=1(2^3+2)=8+2$; thus giving the partitions without repetitions, viz.

$9+1$,
$7+3$,
$7+2+1$,
10,
$5+4+1$,
$5+3+2$,
$6+3+1$,
$6+4$,
$3+4+2+1$,
$8+2$.

To reverse the process it is only necessary to remark that every number is either uneven, or twice an uneven number, or four times an uneven number, or eight times an uneven number, &c., so that every sum of different elements can be uniquely reduced to the form $1+3.\alpha+5.\beta+$&c. (The practical reduction is very easy, *ex. gr.* $14+12+5+3+2$ converts into $7+7+3+3+3+3+5+3+1+1$.) A little consideration shows that no two different partitions of one system can convert into the same partition of the other, so that every partition of either system corresponds uniquely to a partition of the other; and the numbers of partitions in the two systems are thus equal. Several conversions of $P(1,3,5\ldots)n$ are given in the Phil. Mag. for April 1875 (S. 4. vol. xlix. pp. 307–311); but when writing that note I failed to obtain the connexion between the partitions into 1, 3, 5 ... with repetitions and the partitions into 1, 2, 3 ... without repetitions.

II. "On the Development and Succession of the Poison-fangs of Snakes." By CHARLES S. TOMES, M.A. Communicated by JOHN TOMES, F.R.S. Received December 28, 1875.

(Abstract.)

At the conclusion of a paper upon the development of the teeth of Ophidia, published in the first part of the Philosophical Transactions for 1875, I noted that there were peculiarities, which I had not then been able to understand, in the succession and the development of the poison-fangs. Having reviewed the literature of the subject in that and in a preceding paper on the development of Amphibian teeth, I will pass at once to the description of the special features which distinguish the development of poison-fangs. Poisonous snakes are divided into two groups—those which have a shortened movable maxillary bone, which carries the poison-fang and another tooth; and those which have the maxillary bone longer, immovable, and often carrying other teeth behind the poison-fang.

In the former, or viperine poisonous snakes, the poison-fang is very long, and, when out of use, lies recumbent; in the latter, or colubrine poisonous snakes, it is, from the maxillary bone being fixed, constantly erect (Günther's 'Reptiles of British India,' p. 165).

As fresh specimens are indispensable for a complete investigation of developmental peculiarities, I have only been able to examine one of the colubrine group, viz. the Indian cobra.

Of it one may say, roughly speaking, that the poison-fangs are developed just like any other Ophidian teeth, for a description of which I must refer to my former paper, save only that the tooth-germs are necessarily individually modified so as to produce the characteristic canaliculated poison-tooth.

But in all the viperine poisonous snakes which I have examined a strikingly different arrangement is displayed. Upon the movable maxillary bone there is room for two poison-fangs, side by side; and in a macerated skull the tooth in use occupies an extreme position, sometimes on one side, sometimes on the other. In sections displaying all the soft part *in situ*, the remaining space is generally occupied by a tooth which is in process of becoming attached; and, in whatever part of the area of tooth-development the section be taken, the successional teeth are arranged in pairs, in two parallel series. Thus there will be a right-hand series, consisting of the tooth in place and of four successors, and a left-hand series, consisting of the tooth next about to be in place and four successors.

When a tooth of the right-hand series has finished its period of work and is about to be shed, it is succeeded by a tooth of the left-hand series, which comes up by its side, and *vice versâ*. A septum of connective tissue separates the two parallel series, and is continued out into the pouch, which conceals the poison-fangs when at rest, as a free hanging fold: its use appears to be to keep the long axis of the tooth in the right direction prior to its becoming firmly attached, and to prevent a right-hand tooth from getting into the place of one of the left-hand series, and *vice versâ*.

It is obvious that this manner of succession is well adapted to avoid loss of time in the changing of the poison-fangs, for much can be done towards the fixation of a new tooth before the old one is detached. That the succession is both rapid and regular would appear to be indicated by the fact that the successional tooth-sacs are very numerous (often as many as ten), and that they are arranged in pairs, the two being almost absolutely alike in size and stage of development. Now as any given tooth of the one series is succeeded or preceded by its fellow in the other series, one might expect, if any great interval of time were to elapse, that the one would be materially more advanced than the other. When such is not the case, one is led to the inference that the succession is rapid and also regular.

In the cobra, the new tooth has to come into place and become attached after the loss of the old one; and this, it may be inferred, would take much more time. May this not be the explanation of the feat performed by Indian jugglers with the cobra, and their selection of this snake for such purposes? A cobra disarmed would remain harmless for some considerable period; a rattlesnake similarly treated would be furnished with a new weapon very speedily.

I have examined specimens in spirit of a few other colubrine snakes; and although such examination is less satisfactory than the methods which may be pursued with fresh specimens, I believe it will be found to hold good that in those snakes which have a movable maxilla carrying but one tooth, the successional teeth are developed in two parallel series, this being the highest specialization of the poison-apparatus.

On the other hand, in the colubrine poisonous snakes, approximating more nearly to the harmless snakes in having a fixed maxilla, sometimes carrying other teeth in addition to the poison-fang, the successional poison-fangs are developed in a single series, like any other Ophidian teeth.

The development of the individual tooth-germ presents one feature of very great interest. A poison-fang tooth-germ is first formed, like any other, of an extinguisher-shaped enamel-organ (derived from an ingrowth of epithelium, which winds in and out amongst the tooth-sacs) and of a simple conical dentine-pulp.

As it elongates, a groove appears on one side, which, by deepening and by the approximation of its lips, becomes ultimately converted into the poison-canal. The enamel-organ, with its characteristic enamel-cells, passes without break or alteration into this groove; but still lower down is the tooth-germ, where the groove has become very deep; instead of the prismatic enamel-cells constituting a regular pavement epithelium, we have a reticulum of stellate cells, just like that gelatinous stellate tissue which forms so large a part of a mammalian enamel-organ. That the stellate reticulum is a non-essential structure I have previously shown; but the occurrence of such a tissue within the poison-canal, which it wholly occupies, and in which it represents the prismatic enamel-cells found higher up, strongly suggests the idea that it is a sort of retrograde metamorphosis of an active enamel-forming tissue into one which simply fills up a void.

It need hardly be added that a thin layer of enamel is developed upon the outside of the poison-fang; but none is formed on the interior of the poison-canal.

The base of a poison-fang is fluted (this is not the case with other Ophidian teeth), the dentine being convoluted as it is in the base of the tooth of *Varanus* or in a labyrinthodont tooth; and it is attached to the bone through the medium of an opaque, ill-defined, calcified material, beyond which again comes a coarse bone. The fixation of a tooth is effected (alike in cobra and in viperine snakes) by a sort of scaffolding of coarse-textured bone, which is very rapidly thrown out from the surface of its finer textural maxillary bone. This "bone of attachment," met with, as I have elsewhere pointed out, in greater or less quantity wherever teeth are attached by ankylosis, is entirely removed with the fall of a tooth, and is developed afresh for its successor.

III. "On an Integrating Machine having a New Kinematic Principle." By Professor JAMES THOMSON, LL.D., F.R.S.E. Communicated by Prof. Sir WILLIAM THOMSON, F.R.S. Received January 31, 1876.

The kinematic principle for integrating ydx, which is used in the instruments well known as Morin's Dynamometer* and Sang's Planimeter †, admirable as it is in many respects, involves one element of imperfection which cannot but prevent our contemplating it with full satisfaction. This imperfection consists in the sliding action which the edge wheel or roller is required to take in conjunction with its rolling action, which alone is desirable for exact communication of motion from the disk or cone to the edge roller.

The very ingenious, simple, and practically useful instrument well known as Amsler's Polar Planimeter, although different in its main features of principle and mode of action from the instruments just referred to, ranks along with them in involving the like imperfection of requiring to have a sidewise sliding action of its edge rolling wheel, besides the desirable rolling action on the surface which imparts to it its revolving motion—a surface which in this case is not a disk or cone, but is the surface of the paper, or any other plane face, on which the map or other plane diagram to be evaluated in area is drawn.

Professor J. Clerk Maxwell, having seen Sang's Planimeter in the Great Exhibition of 1851, and having become convinced that the combination of slipping and rolling was a drawback on the perfection of the instrument, began to search for some arrangement by which the motion should be that of perfect rolling in every action of the instrument, corresponding to that of combined slipping and rolling in previous instruments. He succeeded in devising a new form of planimeter or integrating machine with a quite new and very beautiful principle of kinematic action depending on the mutual rolling of two equal spheres, each on the other. He described this in a paper submitted to the Royal Scottish Society of Arts in January 1855, which is published in vol. iv. of the Transactions of that Society. In that paper he also offered a suggestion, which appears to be both interesting and important, proposing the attainment of the desired conditions of action by the mutual rolling of a cone and cylinder with their axes at right angles.

---

* Instruments of this kind, and any others for measuring mechanical work, may better in future be called Ergometers than Dynamometers. The name "dynamometer" has been and continues to be in common use for signifying a spring instrument for measuring *force*; but an instrument for measuring *work*, being distinct in its nature and object, ought to have a different and more suitable designation. The name "dynamometer," besides, appears to be badly formed from the Greek, and for designating an instrument for *measurement of force*. I would suggest that the name may with advantage be changed to *dynamimeter*. In respect to the mode of forming words in such cases, reference may be made to Curtius's Grammar, Dr. Smith's English edition, § 354, p. 220.—J. T., 26th February, 1876.

† Sang's Planimeter is very clearly described and figured in a paper by its inventor, in the Transactions of the Royal Scottish Society of Arts, vol. iv. January 12, 1852.

The idea of using pure rolling instead of combined rolling and slipping was communicated to me by Prof. Maxwell, when I had the pleasure of learning from himself some particulars as to the nature of his contrivance. Afterwards (some time between the years 1861 and 1864), while endeavouring to contrive means for the attainment in meteorological observatories of certain integrations in respect to the motions of the wind, and also in endeavouring to devise a planimeter more satisfactory in principle than either Sang's or Amsler's planimeter (even though, on grounds of practical simplicity and convenience, unlikely to turn out preferable to Amsler's in ordinary cases of taking areas from maps or other diagrams, but something that I hoped might possibly be attainable which, while having the merit of working by pure rolling contact, might be simpler than the instrument of Prof. Maxwell and preferable to it in mechanism), I succeeded in devising for the desired object a new kinematic method, which has ever since appeared to me likely sometime to prove valuable when occasion for its employment might be found. Now, within the last few days, this principle, on being suggested to my brother as perhaps capable of being usefully employed towards the development of tide-calculating machines which he had been devising, has been found by him to be capable of being introduced and combined in several ways to produce important results. On his advice, therefore, I now offer to the Royal Society a brief description of the new principle as devised by me.

The new principle consists primarily in the transmission of motion from a disk or cone to a cylinder by the intervention of a loose ball, which presses by its gravity on the disk and cylinder, or on the cone and cylinder, as the case may be, the pressure being sufficient to give the necessary frictional coherence at each point of rolling contact; and the axis of the disk or cone and that of the cylinder being both held fixed in position by bearings in stationary framework, and the arrangement of these axes being such that when the disk or the cone and the cylinder are kept steady, or, in other words, without rotation on their axes, the ball can roll along them in contact with both, so that the point of rolling contact between the ball and the cylinder shall traverse a straight line on the cylindric surface parallel necessarily to the axis of the cylinder—and so that, in the case of a disk being used, the point of rolling contact of the ball with the disk shall traverse a straight line passing through the centre of the disk—or that, in case of a cone being used, the line of rolling contact of the ball on the cone shall traverse a straight line on the conical surface, directed necessarily towards the vertex of the cone. It will thus readily be seen that, whether the cylinder and the disk or cone be at rest or revolving on their axes, the two lines of rolling contact of the ball, one on the cylindric surface and the other on the disk or cone, when both considered as lines traced out in space fixed relatively to the framing of the whole instrument, will be two parallel straight lines, and that the line of motion of the ball's centre will be straight and parallel to them. For facilitating explanations, the motion of the centre of the ball along its path parallel to the axis of the cylinder may be called the ball's longitudinal motion.

Now for the integration of ydx: the distance of the point of contact of the ball with the disk or cone from the centre of the disk or vertex of the cone in the ball's longitudinal motion is to represent y, while the angular space turned by the disk or cone from any initial position represents x; and then the angular space turned by the cylinder will, when multiplied by a suitable constant numerical coefficient, express the integral in terms of any required unit for its evaluation.

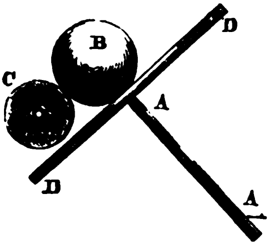
The longitudinal motion may be imparted to the ball by having the framing of the whole instrument so placed that the lines of longitudinal motion of the two points of contact and of the ball's centre, which are three straight lines mutually parallel, shall be inclined to the horizontal sufficiently to make the ball tend decidedly to descend along the line of its longitudinal motion, and then regulating its motion by an abutting controller, which may have at its point of contact, where it presses on the ball, a plane face perpendicular to the line of the ball's motion. Otherwise the longitudinal motion may, for some cases, preferably be imparted to the ball by having the direction of that motion horizontal, and having two controlling flat faces acting in close contact without tightness at opposite extremities of the ball's diameter, which at any moment is in the line of the ball's motion or is parallel to the axis of the cylinder.

It is worthy of notice that, in the case of the disk, ball, and cylinder integrator, no theoretical nor important practical fault in the action of the instrument would be involved in any deficiency of perfect exactitude in the practical accomplishment of the desired condition that the line of motion of the ball's point of contact with the disk should pass through the centre of the disk. The reason of this will be obvious enough on a little consideration.

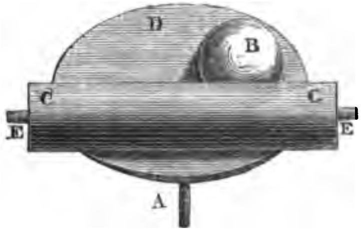
The plane of the disk may suitably be placed inclined to the horizontal at some such angle as 45°; and the accompanying sketch, together with the model, which will be submitted to the Society by my brother, will aid towards the clear understanding of the explanations which have been given.

My brother has pointed out to me that an additional operation, important for some purposes, may be effected by arranging that the machine shall give a continuous record of the growth of the integral by introducing additional mechanisms suitable for continually describing a curve such that for each point of it the abscissa shall represent the value of x, and the ordinate shall represent the integral attained from $x=0$

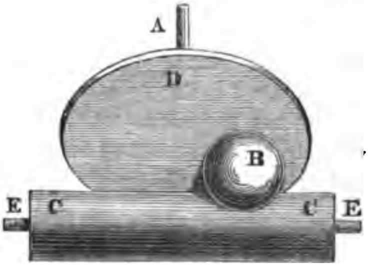
forward to that value of x. This, he has pointed out, may be effected in practice by having a cylinder axised on the axis of the disk, a roll of paper covering this cylinder's surface, and a straight bar situated parallel to this cylinder's axis and resting with enough of pressure on the surface of the primary registering or *the indicating* cylinder (the one, namely,



SIDE ELEVATION.



FRONT ELEVATION.



PLAN.

D, the Disk.
A, the Axle of the Disk.
C, the Cylinder.
E E, the Axle or the Journals of the Cylinder.
B, the Ball.

which is actuated by its contact with the ball) to make it have sufficient frictional coherence with that surface, and by having this bar made to carry a pencil or other tracing point which will mark the desired curve on the secondary registering or *the recording* cylinder. As, from the nature of the apparatus, the axis of the disk and of the secondary registering or the recording cylinder ought to be steeply inclined to the horizontal, and as, therefore, this bar, carrying the pencil, would have the line of its length and of its motion alike steeply inclined with that axis, it seems that, to carry out this idea, it may be advisable to have a thread attached to the bar and extending off in the line of the bar to a pulley, passing over the pulley, and having suspended at its other end a weight which will be just sufficient to counteract the tendency of the rod, in virtue of gravity, to glide down along the line of its own slope, so as to leave it perfectly free to be moved up or down by the frictional coherence between itself and the moving surface of the indicating cylinder worked directly by the ball.

①

IV. "On an Instrument for calculating $\left(\int\phi(x)\psi(x)dx\right)$, the Integral of the Product of two given Functions." By Prof. Sir W. Thomson, LL.D., F.R.S. Received January 28, 1876.

In consequence of the recent meeting of the British Association at Bristol, I resumed an attempt to find an instrument which should supersede the heavy arithmetical labour of calculating the integrals required to analyze a function into its simple harmonic constituents according to the method of Fourier. During many years previously it had appeared to me that the object ought to be accomplished by some simple mechanical means; but it was not until recently that I succeeded in devising an instrument approaching sufficiently to simplicity to promise practically useful results. Having arrived at this stage, I described my proposed machine a few days ago to my brother Professor James Thomson, and he described to me in return a kind of mechanical integrator which had occurred to him many years ago, but of which he had never published any description. I instantly saw that it gave me a much simpler means of attaining my special object than any thing I had been able to think of previously. An account of his integrator is communicated to the Royal Society along with the present paper.

To calculate $\int\phi(x)\psi(x)dx$, the rotating disk is to be displaced from a zero or initial position through an angle equal to $\int_0^x\phi(x)dx$, while the rolling globe is moved so as always to be at a distance from its zero position equal to $\psi(x)$. This being done, the cylinder obviously turns through an angle equal to $\int_0^x\phi(x)\psi(x)dx$, and thus solves the problem.

One way of giving the required motions to the rotating disk and rolling globe is as follows:—

On two pieces of paper draw the curves

$$y=\int_0^x\phi(x)\,dx, \text{ and } y=\psi(x).$$

Attach these pieces of paper to the circumference of two circular cylinders, or to different parts of the circumference of one cylinder, with the axis of x in each in the direction perpendicular to the axis of the cylinder. Let the two cylinders (if there are two) be geared together so as that their circumferences shall move with equal velocities. Attached to the framework let there be, close to the circumference of each cylinder, a slide or guide-rod to guide a movable point, moved by the hand of an operator, so as always to touch the curve on the surface of the cylinder, while the two cylinders are moved round.

Two operators will be required, as one operator could not move the two points so as to fulfil this condition—at all events unless the motion were very slow. One of these points, by proper mechanism, gives an angular motion to the rotating disk equal to its own linear motion, the other gives a linear motion equal to its own to the centre of the rolling globe.

The machine thus described is immediately applicable to calculate the values H_1, H_2, H_3, &c. of the harmonic constituents of a function $\psi(x)$ in the splendid generalization of Fourier's simple harmonic analysis, which he initiated himself in his solutions for the conduction of heat in the sphere and the cylinder, and which was worked out so ably and beautifully by Poisson[*], and by Sturm and Liouville in their memorable papers on this subject published in the first volume of Liouville's 'Journal des Mathématiques.' Thus if

$$\psi(x)=H_1\,\phi_1(x)+H_2\,\phi_2(x)+H_3\,\phi_3(x)+\&c.$$

be the expression for an arbitrary function ψx, in terms of the generalized harmonic functions $\phi_1(x)$, $\phi_2(x)$, $\phi_3(x)$, &c., these functions being such that

$$\int_0^l \phi_1(x)\,\phi_2(x)\,dx=0,\ \int_0^l \phi_1(x)\,\phi_3(x)\,dx=0,\ \int_0^l \phi_2(x)\,\phi_3(x)=0,\ \&c.,$$

we have

$$H_1=\frac{\int_0^l \phi_1(x)\,\psi(x)\,dx}{\int_0^l \{\phi_1(x)\}^2\,dx},$$

$$H_2=\frac{\int_0^l \phi_2(x)\,\psi(x)\,dx}{\int_0^l \{\phi_2(x)\}^2\,dx},$$

&c.

In the physical applications of this theory the integrals which constitute the denominators of the formulæ for H_1, H_2, &c. are always to be evaluated in finite terms by an extension of Fourier's formula for $\int_0^a x\,u_i^2\,dx$ of his problem of the cylinder[†] made by Sturm in equation (10), § iv. of his "Mémoire sur une Classe d'Équations à différences partielles" in Liouville's Journal, vol. i. (1836). The integrals in the numerators are calculated with great ease by aid of the machine worked in the manner described above.

The great practical use of this machine will be to perform the simple harmonic Fourier-analysis for tidal, meteorological, and perhaps even astronomical observations. It is the case in which

$$\phi(x)=\begin{matrix}\sin\\ \cos\end{matrix}(nx);$$

---

[*] His general demonstration of the reality of the roots of transcendental equations essential to this analysis (an exceedingly important step in advance from Fourier's position), which he first gave in the 'Bulletin de la Société Philomathique' for 1828, is reproduced in his 'Théorie Mathématique de la Chaleur,' § 90.

[†] Fourier's 'Théorie Analytique de la Chaleur,' § 319, page 391 (Paris, 1822).

and the integration is performed through a range equal to $\frac{2i\pi}{n}$ (i any integer) that gives this application. In this case the addition of a simple crank mechanism, to give a simple harmonic angular motion to the rotating disk in the proper period $\frac{2\pi}{n}$, when the cylinder bearing the curve $y=\psi(x)$ moves uniformly, supersedes the necessity for a cylinder with the curve $y=\phi(x)$ traced on it, and an operator keeping a point always on this curve in the manner described above. Thus one operator will be enough to carry on the process; and I believe that in the application of it to the tidal harmonic analysis he will be able in an hour or two to find by aid of the machine any one of the simple harmonic elements of a year's tides recorded in curves in the usual manner by an ordinary tide-gauge—a result which hitherto has required not less than twenty hours of calculation by skilled arithmeticians. I believe this instrument will be of great value also in determining the diurnal, semi-diurnal, ter-diurnal, and quarter-diurnal constituents of the daily variations of temperature, barometric pressure, east and west components of the velocity of the wind, north and south components of the same; also of the three components of the terrestrial magnetic force; also of the electric potential of the air at the point where the stream of water breaks into drops in the atmospheric electrometers, and of other subjects of ordinary meteorological or magnetic observations; also to estimate precisely the variation of terrestrial magnetism in the eleven years sun-spot period, and of sun-spots themselves in this period; also to disprove (or prove, as the case may be) supposed relations between sun-spots and planetary positions and conjunctions; also to investigate lunar influence on the height of the barometer, and on the components of the terrestrial magnetic force, and to find if lunar influence is sensible on any other meteorological phenomena—and if so, to determine precisely its character and amount.

From the description given above it will be seen that the mechanism required for the instrument is exceedingly simple and easy. Its accuracy will depend essentially on the accuracy of the circular cylinder, of the globe, and of the plane of the rotating disk used in it.

For each of the three surfaces a much less elaborate application of the method of scraping than that by which Sir Joseph Whitworth has given a true plane with such marvellous accuracy will no doubt suffice for the practical requirements of the instrument now proposed.

V. “Mechanical Integration of the Linear Differential Equations of the Second Order with Variable Coefficients.”

By Prof. Sir William Thomson, LL.D., F.R.S. Received January 28, 1876.

Every linear differential equation of the second order may, as is known, be reduced to the form

$$\frac{d}{dx}\left(\frac{1}{\mathrm{P}}\frac{du}{dx}\right)=u, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where P is any given function of x.

On account of the great importance of this equation in mathematical physics (vibrations of a non-uniform stretched cord, of a hanging chain, of water in a canal of non-uniform breadth and depth, of air in a pipe of non-uniform sectional area, conduction of heat along a bar of non-uniform section or non-uniform conductivity, Laplace's differential equation of the tides, &c. &c.), I have long endeavoured to obtain a means of facilitating its practical solution.

Methods of calculation such as those used by Laplace himself are exceedingly valuable, but are very laborious, too laborious unless a serious object is to be attained by calculating out results with minute accuracy. A ready means of obtaining approximate results which shall show the general character of the solutions, such as those so well worked out by Sturm[*], has always seemed to me a desideratum. Therefore I have made many attempts to plan a mechanical integrator which should give solutions by successive approximations. This is clearly done now, when we have the instrument for calculating $\int \phi(x)\,\psi(x)\,dx$, founded on my brother's disk-, globe-, and cylinder-integrator, and described in a previous communication to the Royal Society; for it is easily proved[†] that if

$$\left.\begin{aligned} u_2&=\int_0^x \mathrm{P}\,(\mathrm{C}-\int_0^x u_1dx)\,dx,\\ u_3&=\int_0^x \mathrm{P}\,(\mathrm{C}-\int_0^x u_2dx)\,dx,\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\&\text{c.},$$

where u_1 is any function of x, to begin with, as for example $u_1=x$; then u_2, u_3, &c. are successive approximations converging to that one of the solutions of (1) which vanishes when $x=0$.

Now let my brother's integrator be applied to find $\mathrm{C}-\int_0^x u_1dx$, and let its result feed, as it were, continuously a second machine, which shall find the integral of the product of its result into P dx. The second machine will give out continuously the value of u_2. Use again the same process with u_2 instead of u_1, and then u_3, and so on.

---

[*] “Mémoire sur les équations différentielles linéaires du second ordre,” Liouville's Journal, vol. i. 1836.

[†] Cambridge Senate-House Examination, Thursday afternoon, January 22nd, 1874.

After thus altering, as it were, u_1 into u_2 by passing it through the machine, then u_2 into u_3 by a second passage through the machine, and so on, the thing will, as it were, become refined into a solution which will be more and more nearly rigorously correct the oftener we pass it through the machine. If u_{i+1} does not sensibly differ from u_i, then each is sensibly a solution.

So far I had gone and was satisfied, feeling I had done what I wished to do for many years. But then came a pleasing surprise. Compel agreement between the function fed into the double machine and that given out by it. This is to be done by establishing a connexion which shall cause the motion of the centre of the globe of the first integrator of the double machine to be the same as that of the surface of the second integrator's cylinder. The motion of each will thus be necessarily a solution of (1). Thus I was led to a conclusion which was quite unexpected; and it seems to me very remarkable that the general differential equation of the second order with variable coefficients may be rigorously, continuously, and in a single process solved by a machine.

Take up the whole matter *ab initio*: here it is. Take two of my brother's disk-, globe-, and cylinder-integrators, and connect the fork which guides the motion of the globe of each of the integrators, by proper mechanical means, with the circumference of the other integrator's cylinder. Then move one integrator's disk through an angle $=x$, and simultaneously move the other integrator's disk through an angle always $=\int_0^x \mathrm{P}\,dx$, a given function of x. The circumference of the second integrator's cylinder and the centre of the first integrator's globe move each of them through a space which satisfies the differential equation (1).

To prove this, let at any time g_1, g_2 be the displacements of the centres of the two globes from the axial lines of the disks; and let dx, $\mathrm{P}dx$ be infinitesimal angles turned through by the two disks. The infinitesimal motions produced in the circumferences of two cylinders will be

$$g_1 dx \text{ and } g_2 \mathrm{P}\,dx.$$

But the connexions pull the second and first globes through spaces respectively equal to those moved through by the circumferences of the first and second cylinders. Hence

$$g_1 dx = dg_2, \text{ and } g_2 \mathrm{P}\,dx = dg_1;$$

and eliminating g_2,

$$\frac{d}{dx}\left(\frac{1}{\mathrm{P}}\frac{dg_1}{dx}\right)=g_1,$$

which shows that g_1 put for u satisfies the differential equation (1).

The machine gives the complete integral of the equation with its two arbitrary constants. For, for any particular value of x, give arbitrary values G_1, G_2. [That is to say mechanically; disconnect the forks from the cylinders, shift the forks till the globes' centres are at distances G_1, G_2 from the axial lines, then connect, and move the machine.]

We have for this value of x,

$$g_1 = G_1,\text{ and }\frac{dg_1}{dx} = G_2 P;$$

that is, we secure arbitrary values for g_1 and $\frac{dg_1}{dx}$ by the arbitrariness of the two initial positions G_1, G_2 of the globes.

VI. "Mechanical Integration of the general Linear Differential Equation of any Order with Variable Coefficients." By Prof. Sir WILLIAM THOMSON, LL.D., F.R.S. Received January 28, 1876.

Take any number i of my brother's disk-, globe-, and cylinder-integrators, and make an integrating chain of them thus:—Connect the cylinder of the first so as to give a motion equal to its own* to the fork of the second. Similarly connect the cylinder of the second with the fork of the third, and so on. Let g_1, g_2, g_3, up to g_i, be the positions† of the globes at any time. Let infinitesimal motions $P_1 dx$, $P_2 dx$, $P_3 dx$, ... be given simultaneously to all the disks (dx denoting an infinitesimal motion of some part of the mechanism whose displacement it is convenient to take as independent variable). The motions ($d\kappa_1$, $d\kappa_2$, ... $d\kappa_i$) of the cylinders thus produced are

$$d\kappa_1 = g_1 P_1 dx,\ d\kappa_2 = g_2 P_2 dx, \dots d\kappa_i = g_i P_i dx. \quad . \quad . \quad . \quad (1)$$

But, by the connexions between the cylinders and forks which move the globes, $d\kappa_1 = dg_2$, $d\kappa_2 = dg_3$, ... $d\kappa_{i-1} = dg_i$; and therefore

and

$$\left.\begin{array}{l} dg_2 = g_1 P_1 dx,\ dg_3 = g_2 P_2 dx, \dots dg_i = g_{i-1} P_{i-1} dx \\ d\kappa_i = g_1 P_1 dx,\ d\kappa_2 = g_2 P_2 dx, \dots d\kappa_i = g_i P_i dx. \end{array}\right\} \quad . \quad . \quad (2)$$

Hence

$$g_1 = \frac{1}{P_1}\frac{d}{dx}\frac{1}{P_2}\frac{d}{dx} \cdots \frac{1}{P_{i-1}}\frac{d}{dx}\frac{1}{P_i}\frac{dx_i}{dx}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Suppose, now, for the moment that we couple the last cylinder with the first fork, so that their motions shall be equal—that is to say, $\kappa_i = g_1$. Then, putting u to denote the common value of these variables, we have

---

* For brevity, the motion of the circumference of the cylinder is called the cylinder's motion.

† For brevity, the term "position" of any one of the globes is used to denote its distance, positive or negative, from the axial line of the rotating disk on which it presses.

$$u = \frac{1}{P_1}\frac{d}{dx}\frac{1}{P_2}\frac{d}{dx}\cdots\frac{1}{P_{i-1}}\frac{d}{dx}\frac{1}{P_i}\frac{du}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

Thus an endless chain or cycle of integrators with disks moved as specified above gives to each fork a motion fulfilling a differential equation, which for the case of the fork of the ith integrator is equation (4). The differential equations of the displacements of the second fork, third fork, . . . $(i-1)$th fork may of course be written out by inspection from equation (4).

This seems to me an exceedingly interesting result; but though $P_1, P_2, P_3, \ldots P_i$ may be any given functions whatever of x, the differential equations so solved by the simple cycle of integrators cannot, except for the case of $i=2$, be regarded as the general linear equation of the order i, because, so far as I know, it has not been proved for any value of i greater than 2 that the general equation, which in its usual form is as follows,

$$Q_1\frac{d^i u}{dx^i} + Q_2\frac{d^{i-1}u}{dx^{2-1}} + \ldots Q_i\frac{du}{dx} - u = 0, \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

can be reduced to the form (4). The general equation of the form (5), where $Q_1, Q_2, \ldots Q_i$ are any given forms of x, may be integrated mechanically by a chain of connected integrators thus:—

First take an open chain of i simple integrators as described above, and simplify the movement by taking $P_1 = P_2 = P_3 = \ldots = P_2 = 1$, so that the speeds of all the disks are equal, and dx denotes an infinitesimal angular motion of each. Then by (2) we have

$$g_i = \frac{d\kappa_i}{dx},\ g_{i-1} = \frac{d^2\kappa_i}{dx^2}, \ldots, g_2 = \frac{d^{i-2}\kappa_i}{dx^{i-2}},\ g_1 = \frac{d^i\kappa_i}{dx^i} \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

Now establish connexions between the i forks and the ith cylinder, so that

$$Q_1 g_1 + Q_2 g_2 + \ldots + Q_{i-1}g_{i-1} + Q_i g_i = \kappa_i \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

Putting in this for g_1, g_2, &c. their values by (6), we find an equation the same as (5), except that κ_i appears instead of u. Hence the mechanism, when moved so as to fulfil the condition (7), performs by the motion of its last cylinder an integration of the equation (5). This mechanical solution is complete; for we may give arbitrarily any initial values to $\kappa_i, g_i, g_{i-1}, \ldots g_3, g_2$; that is to say, to

$$u,\ \frac{du}{dx},\ \frac{d^2u}{dx^2}, \ldots \frac{d^{i-1}u}{dx^{2-1}}.$$

Until it is desired actually to construct a machine for thus integrating differential equations of the third or any higher order, it is not necessary to go into details as to plans for the mechanical fulfilment of condition (7); it is enough to know that it can be fulfilled by pure mechanism working continuously in connexion with the rotating disks of the train of integrators.

ADDENDUM. Received February 10, 1876.

The integrator may be applied to integrate any differential equation of any order. Let there be i simple integrators; let x_1, g_1, κ_1 be the displacements of disk, globe, and cylinder of the first, and so for the others. We have

$$g_1 = \frac{d\kappa_1}{dx_1},\ g_2 = \frac{d\kappa_2}{dx_2},\ \&c.$$

Now by proper mechanism establish such relations between

$$x_1, g_1, \kappa_1, x_2, g_2, \&c.$$

that

$$f^{(1)}(x_1, g_1, \kappa_1, x_2, \ldots) = 0,$$

$$f^{(2)}(x_1, g_1, \kappa_1, x_2, \ldots) = 0,$$

$$\cdots\cdots\cdots\cdots$$

$$f^{(2i-1)}(x_1, g_1, \kappa_1, x_2, \ldots) = 0$$

($2i-1$ relations).

This will leave just one degree of freedom; and thus we have $2i-1$ simultaneous equations solved. As one particular case of relations take

$$x_1 = x_2 = \ldots\ (i-2 \text{ relations}),$$

and

$$g_2 = \kappa_1,\ g_3 = \kappa_2,\ \&c.\ (i-2 \text{ relations});$$

so that

$$g_1 = \frac{d^i\kappa}{dx^i},\ g_2 = \frac{d^{i-1}\kappa_i}{dx^{i-1}}.$$

Thus one relation is still available. Let it be

$$f(x, g_1, g_2, \ldots g_i, \kappa_i) = 0.$$

Thus the machine solves the differential equation

$$f\left(x, \frac{d^iu}{dx^i}, \frac{d^{i-1}u}{dx^{i-1}}, \ldots \frac{du}{dx}, u\right) = 0 \text{ (putting } u \text{ for } \kappa_i).$$

Or again, take $2i$ double integrators. Let the disks of all be connected so as to move with the same speed, and let t be the displacement of any one of them from any particular position. Let

$$x,\, y,\, x',\, y',\, x'',\, y'', \ldots x^{(i-1)},\, y^{(i-1)}$$

be the displacements of the second cylinders of the several double integrators. Then (the second globe-frame of each being connected to its first cylinder) the displacements of the first globe-frames will be

$$\frac{d^2x}{dt^2},\, \frac{d^2y}{dt^2},\, \frac{d^2x'}{dt^2},\, \frac{d^2y'}{dt^2},\, \&c.$$

Let now X, Y, X′, Y′, &c. be each a given function of

$$x,\, y,\, x',\, y',\, x'',\, \&c.$$

By proper mechanism make the first globe of the first double integrator-frame move so that its displacement shall be equal to X, and so on. The machine then solves the equations

$$\frac{d^2x}{dt^2}=\mathrm{X},\, \frac{d^2y}{dt^2}=\mathrm{Y},\, \frac{d^2x}{dt^2}=\mathrm{X}',\, \&c.$$

For example, let

$$\begin{aligned} \mathrm{X}=&(x'-x)f\{(x'-x)^2+(y'-y)^2\}\\ &+(x''-x)f\{(x''-x)^2+(y''-y)^2\}\\ &+\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\\ \mathrm{Y}=&(y'-y)f\{x'-x)^2+(y'-y)^2\}\\ &+(y''-y)f\{(x''-x)^2+(y''-y)^2\}\\ &+\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\\ \mathrm{X}'=&\&c.,\ \mathrm{Y}'=\&c., \end{aligned}$$

where f denotes any function.

Construct in (frictionless) steel the surface whose equation is

$$z=\xi f(\xi^2+\eta^2)$$

(and repetitions of it, for practical convenience, though *one* theoretically suffices). By aid of it (used as it were a cam, but for two independent variables) arrange that one moving auxiliary piece (an x-auxiliary I shall call it), capable of moving to and fro in a straight line, shall have displacement always equal to

$$(x'-x)f\{(x'-x)^2+(y'-y)^2\},$$

that another (a y-auxiliary) shall have displacement always equal to

$$(y'-y)f\{(x'-x)^2+(y'-y)^2\},$$

that another (an x-auxiliary) shall have displacement equal to

$$(x''-x)f\{(x''-x)^2+(y''-y)^2\},$$

and so on.

Then connect the first globe-frame of the first double integrator, so that its displacement shall be equal to the sum of the displacements of the x-auxiliaries; that is to say, to

$$\begin{aligned}&(x'-x)f\{(x'-x)^2+(y'-y)^2\}\\&+(x'-x)f\{x''-x)^2+(y''-y)^2\}\\&+\&c.\end{aligned}$$

This may be done by a cord passing over pulleys attached to the x-auxiliaries, with one end of it fixed and the other attached to the globe-frame (as in my tide-predicting machine, or in Wheatstone's alphabetic telegraph-sending instrument).

Then, to begin with, adjust the second globe-frames and the second cylinders to have their displacements equal to the initial velocity-components and initial coordinates of i particles free to move in one plane. Turn the machine, and the positions of the particles at time t are shown by the second cylinders of the several double integrators, supposing them to be free particles attracting or repelling another with forces varying according to any function of the distance.

The same may clearly be done for particles moving in three dimensions of space, since the components of force on each may be mechanically constructed by aid of a cam-surface whose equation is

$$z=\xi f(\eta)$$

and taking η for the distance between any two particles, and

$$\begin{aligned}\xi&=x'-x\\ \text{or}\quad&=y'-y\\ \text{or}\quad&=x''-x,\ \&c.\end{aligned}$$

Thus we have a complete mechanical integration of the problem of finding the free motions of any number of mutually influencing particles, not restricted by any of the approximate suppositions which the analytical treatment of the lunar and planetary theories requires.

February 10, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Right Hon. Lord Aberdare and the Right. Hon. George Sclater-Booth were admitted into the Society.

The Right Hon. Benjamin Disraeli, whose Certificate had been suspended, as required by the Statutes, was balloted for and elected a Fellow of the Society.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On Repulsion resulting from Radiation."—Part III. By William Crookes, F.R.S. &c. Received January 5, 1876.

(Abstract.)

This paper contains an account of experiments on the action of radiation on bodies the surfaces of which have their radiating and absorbing powers modified by various coatings. The difference between a white and a lampblacked surface in this respect was at first not very decided; and experiments have been instituted with the object of clearing up some anomalies observed in the actions. Two pith disks, one white and the other black, were suspended on a light arm in a glass bulb by means of a fine silk fibre; after perfect exhaustion the white and black disks were found to be equally repelled by heat of low intensity, such as from the fingers, warm water, &c. A copper ball was then tried at gradually increasing temperatures. Up to 250° C. it repelled both equally, above that the black was more repelled than the white, and at a full red heat the repulsion of the black disk was very energetic. A lighted candle acts with more energy than the red-hot copper.

The presence of even a small quantity of aqueous vapour in the exhausted apparatus almost, if not quite, neutralizes the more energetic action which luminous rays appear to exert on a blackened surface.

After describing several different modifications and some new forms of apparatus devised to facilitate experiment, the author gives a drawing of an instrument which enables him to get quantitative measurements of the amount of incident light falling on it. It consists of a flat bar of pith, half black and half white, suspended horizontally in a bulb by means of a long silk fibre. A small magnet and reflecting-mirror are fastened to the pith, and a controlling magnet is fastened outside so that it can slide up and down the tube, and thus increase or diminish

sensitiveness. The whole is completely exhausted, and then enclosed in a box lined with black velvet, with apertures for the rays of light to pass in and out. A ray of light reflected from the mirror on to a graduated scale, shows the movements of the pith bar. The degrees of deflection produced by the light of a candle at distances from 6 feet to 35 feet are given.

The experimental observations and the numbers which are required by the theoretical diminution of light with the square of the distance are sufficiently close, as the following figures show:—

Candle	6 feet off	gives	a deflection of	218°
,,	12	,,	,,	54
,,	18	,,	,,	24·5
,,	24	,,	,,	13
,,	10	,,	,,	77
,,	20	,,	,,	19
,,	30	,,	,,	8·5

The effect of two candles side by side is practically double, and of three candles three times that of one candle.

The action of various solid and liquid screens is next given.

A candle 3 feet off, giving a deflection of 180°, has its action reduced to the following amounts by

Yellow glass	161°
Blue ,,	102
Green ,,	101
Red ,,	128
Water	47
Alum	27

A candle on each side of the apparatus, and equidistant from it, keeps the index ray of light at zero; by shading off either one or the other the light flies off to either extremity of the scale. This gives a ready means of balancing two sources of light one against the other. Thus, retaining the standard candle 48 inches off on the left of the bar, the index was brought to zero by placing on the right

2 candles	67	inches off,
1 candle behind solution of sulphate of copper	6	,,
,, ,, alum plate	14	,,
A small gas-burner	113	,,

These experiments show how conveniently and accurately this instrument can be used as a photometer. By balancing a standard candle on one side against any source of light on the other, the value of the latter in terms of a candle is readily shown; thus in the last experiment the standard candle 48 inches off was balanced by a gas-flame 113 inches off. The lights were therefore in the proportion of 48^2 to 113^2, or as 1 to 5½. The gas-burner was therefore equal to 5½ candles.

By interposing screens of water or plates of alum, and so practically cutting off all the dark heat, the actual luminosity is measured. In addition to this, by interposing coloured glasses or solutions, any desired colours can be measured either against the total radiation from a candle, its luminous rays, or any desired colour. One coloured ray can be balanced against another coloured ray, by having differently coloured screens on either side.

The variations in the luminosity of a "standard" candle will cease to be of importance. Any candle may be taken; and if it be placed at such a distance from the apparatus that it will give a uniform deflection, say of 100 divisions, the standard can be reproduced at any subsequent time; and the burning of the candle may be tested during the photometric experiments by taking the deflection it causes from time to time, and altering its distance, if needed, to keep the deflection at 100 divisions.

If the pith bar in this instrument be blacked on alternate halves, an impetus given by a ray of light always acts in the same direction of movement. A candle causes it to spin round very rapidly until the suspending fibre is twisted up, and the rotation is stopped by the accumulated torsion.

By arranging the apparatus so that the black and white surfaces are suspended on a pivot instead of by a silk fibre, the interfering action of torsion is removed, and the instrument will rotate continuously under the influence of radiation. To this instrument the author has given the name of the "Radiometer," or "Light-Mill." It consists of four arms of very fine glass, supported in the centre by a needle-point, and having at the extremities thin disks of pith lampblacked on one side, the black surfaces all facing the same way. The needle stands in a glass cup, and the arms and disks are delicately balanced so as to revolve with the slightest impetus.

In the 'Proceedings of the Royal Society' for 1875 (vol. xxiii. p. 373), the author gave a brief account of some of the earlier experiments with these instruments. In the present paper he enters very fully into the various phenomena presented by them, and gives Tables showing the number of revolutions made by the radiometer when exposed to a constant source of light removed different distances from the instrument. The law is that the rapidity of revolution is inversely as the square of the distance between the light and the instrument.

When exposed to different numbers of candles at the same distance off, the number of revolutions in a given time are in proportion to the number of candles, two candles giving twice the rapidity of one candle, and three giving three times, &c.

The position of the light in the horizontal plane of the instrument is of no consequence, provided the distance is not altered; thus two candles one foot off give the same number of revolutions per second, whether they are side by side or opposite to each other. From this it follows that if the radiometer is brought into a uniformly lighted space it will continue to revolve. This is proved to be the case by experiment.

The speed with which a sensitive radiometer will revolve in full sunshine is almost incredible. Nothing is apparent but an undefined nebulous ring, which becomes at times almost invisible. The number of revolutions per second cannot be counted, but it must be several hundreds, for one candle will make the arms spin round forty times a second.

The action of dark heat (*i. e.* from boiling water) is to repel each surface equally, and the movement of the radiometer is therefore arrested if a flask of boiling water is brought near it. The same effect is produced by ice.

From some observations made by the author, it appears probable that heat of a still lower refrangibility repels the white more than it does the black surface. Many instances are given of the radiometer revolving the reverse way. Thus breathing gently on the instrument will generally cause this effect to be produced.

An experiment is described with a radiometer the moving parts of which are of aluminium, blacked on one side. When exposed to the radiation from a candle the arms revolve the normal way. On removing the candle they revolve the reverse way. Heated with a Bunsen burner the arms revolve the normal way as they are getting hot; but as soon as the source of heat is removed and cooling commences, rotation sets up in the reverse way, and continues with great energy till the whole is cold. The reverse movement during the cooling is apparently equal in energy to the normal movement as it is being heated.

It is easy to get rotation in a radiometer without having the surfaces of the disks differently coloured. An experiment is described with one having the pith disks blacked on both sides. On bringing a candle near it, and shading the light from one side, rapid rotation is produced, which is at once altered in direction by moving the shade to the other side.

The author describes many forms of radiometer, by means of which the movements can be exhibited to a large audience, or can be made to record themselves telegraphically on a self-recording instrument.

II. "On Repulsion resulting from Radiation."—Part IV. By WILLIAM CROOKES, F.R.S. &c. Received February 5, 1876.

(Abstract.)

In this paper the author describes experiments on the repulsion produced by the different rays of the solar spectrum. The apparatus employed is the horizontal beam suspended by a glass fibre and having

square pieces of pith at each end coated with lampblack. The whole is fitted up and hermetically sealed in glass, and connected with an improved mercury-pump. In front of the square of pith at one end a quartz window is cemented to the apparatus; and the movements of the beam, when radiation falls on the pith, are observed by a reflected ray of light on a millimetre-scale. The apparatus was fitted up in a room specially devoted to it, and was protected on all sides, except where the rays of light had to pass, with cotton-wool and large bottles of water. A heliostat reflected in a constant direction a beam of sunlight, which was received on an appropriate arrangement of slit, lenses, and prisms for projecting a pure spectrum. Results were obtained in the months of July, August, and September; and they are given in the paper graphically as a curve, the maximum being in the ultra-red, and the minimum in the ultra-violet. Taking the maximum at 100, the following are the mechanical values of the different colours of the spectrum :—

Ultra-red	100
Extreme red	85
Red	73
Orange	66
Yellow	57
Green	41
Blue	22
Indigo	8½
Violet	6
Ultra-violet	5

A comparison of these figures with those usually given in text-books to represent the distribution of heat in the spectrum is a sufficient proof that the mechanical action of radiation is as much a function of the luminous rays as it is of the dark heat-rays.

The author discusses the question, "Is the effect due to heat or to light?" There is no real difference between heat and light; all we can take account of is difference of wave-length; and a ray of a definite refrangibility cannot be split up into two rays, one being heat and one light. Take, for instance, a ray of definite refrangibility in the red. Falling on a thermometer it shows the action of heat, on a thermopile it produces an electric current, to the eye it appears as light and colour, on a photographic plate it causes chemical action, and on the suspended pith it causes motion. But all these actions are inseparable attributes of the ray of that particular wave-length, and are not evidence of separate identities.

The author enters into some theoretical explanations of the action of the different parts of the spectrum but these cannot well be given in abstract.

An experiment is described by which sunlight was filtered through alum, glass, and water screens, so as to cut off the whole of the ultra-red or dark-heat rays. The ray of light which was thus freed from dark heat was allowed to fall on the pith surface of the torsion-apparatus, when it produced a deflection of 105°. On interposing a solution of iodine in disulphide of carbon the deflection fell to 2°, showing that the previous action was almost entirely due to *light*. With a candle tried under the same circumstances, the light filtered from dark heat produced a deflection of 37°, which was reduced to 5° by interposing the opaque solution of iodine.

In order to obtain comparative results among disks of pith coated with lampblack and with other substances, a torsion-apparatus was constructed in which two or more disks could be exposed one after the other to a standard light. One disk always being lampblacked pith, the other disks could be changed so as to get comparisons of action. If the action of radiation from a candle on the lampblacked disk be taken as 100, the following are the proportions obtained:—

On Lampblacked pith	100
Iodide of palladium	87·3
Precipitated silver	56
Amorphous phosphorus	40
Sulphate of baryta	37
Milk of sulphur	31
Red oxide of iron	28
Scarlet iodide of mercury and copper	22
Lampblacked silver	18
White pith	18
Carbonate of lead	13
Rock-salt	6·5
Glass	6·5

In consequence of some experiments tried by Profs. Tait and Dewar, and published in 'Nature,' July 15, 1875, the author fitted up a very sensitive apparatus for the purpose of carefully examining the action of radiation on alum, rock-salt, and glass. The source of radiation was a candle. Perfectly transparent and highly polished plates of the same size were used, and the deflection was made evident by an index ray of light. Taking the action on the alum at 100, that on the rock-salt in five successive experiments was 81, 77·3, 71, 62·5, 60·4. This increasing action on the alum was found to be caused by efflorescence, which took place rapidly in the vacuum, and rendered the crystal partially opaque. A fresh alum plate being taken, this and the rock-salt were coated with lampblack and replaced in the apparatus, the black side away from the source of radiation, so that the radiation would pass through the crystal before reaching the lampblack. The action of radiation was in the proportion of blacked alum 100 to blacked rock-salt 73.

Rock-salt and glass were next tested against each other *in vacuo* in a torsion-balance. Professors Dewar and Tait say that rock-salt is inactive when the beam from a candle is thrown on it, while a glass disk is active. The author has failed to corroborate these results; he found the mean of several concordant observations to be—rock-salt 39, glass 40.

The Measurement of the Force.

The author describes a torsion-balance in which he is enabled to weigh the force of radiation from a candle, and give it in decimals of a grain. The principle of the instrument is that of W. Ritchie's torsion-balance, described in the Philosophical Transactions for 1830. The construction is somewhat complicated, and cannot be well described without reference to the diagrams which accompany the original paper. A light beam, having two square inches of pith at one end, is balanced on a very fine fibre of glass stretched horizontally in a tube, one end of the fibre being connected with a torsion-handle passing through the tube, and indicating angular movements on a graduated circle. The beam is cemented to the torsion-fibre, and the whole is enclosed in glass and connected with the mercury-pump and exhausted as perfectly as possible. A weight of 0·01 grain is so arranged that it can be placed on the pith or removed from it at pleasure. A ray of light from a lamp reflected from a mirror in the centre of the beam to a millimetre-scale 4 feet off shows the slightest movement. When the reflected ray points to zero, a turn of the torsion-handle in one or the other direction will raise or depress the pith end of the beam, and thus cause the index ray to travel along the scale to the right or to the left. If a small weight is placed on one end so as to depress it, and the torsion-handle is then turned, the tendency of the glass fibre to untwist itself will ultimately balance the downward pressure of the weight, and will again bring the index ray to zero. It was found that when the weight of the $\frac{1}{100}$ of a grain was placed on the pith surface, the torsion-handle had to be turned 27 revolutions and 353°, or 10073° before the beam became horizontal. The downward pressure of the $\frac{1}{100}$ of a grain was therefore equivalent to the force of torsion of the glass thread when twisted through 10073°.

The author next ascertained what was the smallest amount of weight which the balance would indicate. He found that 1° of torsion gave a very decided movement of the index ray of light, a torsion of 10073° balancing the $\frac{1}{100}$ of a grain, while 10074° overbalanced it. The balance will therefore turn to the $\frac{99}{100,000,000}$ of a grain.

Divide a grain weight into a million parts, place one of them on the pan of the balance, and the beam will be instantly depressed.

Weighed in this balance the mechanical force of a candle 12 inches off was found to be 0·000444 grain; of a candle 6 inches off 0·001772 grain. At half the distance the weight of radiation should be four times, or 0·001776 grain; the difference between theory and experiment being only four millionths of a grain is a sufficient proof that the indications of this instrument, like those of the apparatus previously described by the author, follow rigidly the law of inverse squares. An examination of the differences between the separate observations and the mean shows that the author's estimate of the sensitiveness of his balance is not excessive, and that in practice it will safely indicate the millionth of a grain.

One observation of the weight of sunlight is given; it was taken on December 13; but the sun was so obscured by thin clouds and haze that it was only equal to 10·2 candles 6 inches off. Calculating from this datum, it is seen that the pressure of sunshine is 2·3 tons per square mile.

The author promises further observations with this instrument, not only in photometry and in the repulsion caused by radiation, but in other branches of science in which the possession of a balance of such incredible delicacy is likely to furnish valuable results.

February 17, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Researches upon the Specific Volumes of Liquids." By T. E. Thorpe, Ph.D., F.R.S.E., Professor of Chemistry in the Yorkshire College of Science, Leeds. Communicated by Prof. A. W. Williamson, For. Sec. R.S. Received January 14, 1876.

II. *On the Specific Volumes of certain similarly constituted Inorganic Chlorides.*

The results of the observations made by Pierre and Kopp upon the boiling-points, specific gravities, and thermal expansibilities of the trichlorides and tribromides of phosphorus, arsenic, and antimony have led Kopp to suppose that the specific volumes of phosphorus, arsenic, and antimony, in their liquid combinations, may be identical. The same conclusion has been drawn with respect to tin, titanium, and silicon from Pierre's observations upon the tetrachlorides of these elements[*].

---

[*] Ann. der Chem. u. Pharm. xcvi. p. 319. In his original paper Kopp remarks that the specific volume of antimony, from his observations on the chloride, $SbCl_3$, and the bromide, $SbBr_3$, is decidedly larger than that of phosphorus and arsenic. But the larger value is in part due to the atomic weight of antimony being taken as 129. If the more

The common value of P, As, and Sb would appear to be about 27; that of Si, Ti, and Sn about 35. But on examining the details of the observations, it becomes evident that this conclusion is not strictly borne out by the results; the numbers obtained for the individual members of the group differ in many cases considerably from the common value, the divergences being far wider than could arise from errors of observation, either in the determination of the physical constants or in the estimation of the atomic weights of the constituent bodies. In fact the order of the divergences would seem to render it probable that the specific volumes of the several members of a family of elements increase with their atomic weights.

In a former communication to the Royal Society I have given the results of a series of observations on the specific gravities, boiling-points, and rate of expansion of certain liquid chlorides of phosphorus*. Since Roscoe has shown that vanadium is a member of the phosphorus group of elements, it has appeared to me that a comparison of the specific volumes of the analogously constituted phosphoryl and vanadyl trichlorides might serve to throw additional light on this question of the relation of the specific volumes of the members of a family of elements to their atomic weights.

Methods of observation.—A detailed account of the methods of observation and of reduction and calculation employed in this series of researches is reserved for a subsequent communication; but in order to render certain of the data given in this paper more intelligible, it may be desirable to state that the rates of expansion of the various liquids have been determined in thermometer-shaped vessels (dilatometers), graduated and accurately calibrated. The readings were made with a telescope provided with a micrometer eyepiece. Three series of thermometers were employed, two of which were obtained from Mr. Casella, and the third from Dr. Geissler, of Bonn; for a description of these instruments I refer to the paper by Prof. Rücker and myself on the "Expansion of Sea-water by Heat"†.

All observations of temperature, unless otherwise stated, are converted into air-thermometer degrees by means of Regnault's and Recknagel's Tables‡. In the determination of the boiling-points the bulb of the thermometer was placed in the vapour of the liquid. I mention this fact as serving to account for the discrepancy in the numbers given by Pierre and myself, Pierre's observations being made with the bulb in the liquid.

---

probable number 122·3 (Dexter, Kessler) be adopted, the specific volume is found to approximate more nearly to that of phosphorus and arsenic; at least the variation from the mean value for the two last-named elements is less than the difference between the specific volumes of tin and titanium, which are regarded by Kopp as practically identical.

* Proc. Roy. Soc. vol. xxiii. p. 364. Ber. Deut. Chem. Gesell. 1875, p. 326.

† *Antè*, p. 159.

‡ Wüllner's Lehrbuch der Physik. Pogg. Ann. cxxiii. p. 115.

Due precaution was taken to ensure regular ebullition and to prevent overheating. In correcting the indications of the thermometer for the cooled portion of the column, I have made use of a special series of observations to obtain the value of δ in the well-known expression

$$T = t + \delta(t - t')n,$$

in which

t = the observed temperature on the thermometer,

t' = the mean temperature of the cooled column,

n = the length of column, measured in degrees, possessing the temperature t',

δ = a constant, usually taken as ·000154, *i.e.* the value of the apparent expansion of mercury in glass for 1°,

since it is evident, as pointed out by Holtzmann and by Wüllner and Landolt[*], that by taking $\delta = \cdot000154$ the results are over-corrected when n is small. The barometric observations are corrected and reduced by the aid of Schumacher's Tables. The corrected boiling-points are reduced to the uniform pressure of 760 millims. by means of the formula

$$0{\cdot}0375^\circ(760 - h),$$

in which h is the actual height of the barometer at the time of observation. As is well known, this expression does not afford absolutely accurate results, since the relation of the boiling-point to pressure differs with each liquid; nevertheless the results are more nearly comparable by adopting it than by neglecting it altogether. In one or two cases I have reduced the indications by the aid of data derived from vapour-tension observations when these have been to hand, the difference between the results thus afforded and those obtained by means of the formula above given has never exceeded 0°·05 C.; hence we may assume that for the ordinary range of barometric pressure the formula is generally applicable.

The specific gravities of the various liquids were taken at the temperature of melting ice, and are compared with water at 4°. The weighings were made by the method of vibrations, and are reduced to a vacuum. The results thus obtained, and also those calculated for the boiling-points, express the weights in grams of 1 cubic centimetre of the several liquids at these temperatures. The values given for the specific volumes indicate therefore the volume in cubic centimetres of equivalent weights in grams of the respective liquids at their boiling-points.

I. *Phosphoryl Trichloride.*

Prepared by heating phosphorus pentachloride with phosphorus pentoxide. The product commenced to boil at 107°, the greater portion distilling at 107°·5 (uncor.), under a barometric pressure of 755·2 millims. Since this boiling-point is about 2°·5 lower than that usually assigned to this compound, I solidified the chloride in a freezing-mixture of ice and salt, allowed it to melt partially, and poured away the liquid portion. This operation was repeated several times in order to remove any trichloride which might possibly be present. The boiling-point of the chloride was, however, unaltered by this treatment; the liquid distilled completely between 107° and 107°·5, the greater portion boiling at 107°·30, under a pressure of 751 millims. Corrected and reduced boiling-point 107°·23.

---

[*] Ann. der. Chem. u. Pharm. Suppl. 1867–68, p. 140.

A second preparation made by Gerhardt's method, *i. e.* by heating phosphorus pentachloride with crystallized boric acid, boiled at 107°·4, under a pressure of 765 millims. Corrected boiling-point 107°·22.

The first sample was analyzed with the following results:—

I.	Weight of $POCl_3$	*in vacuo*	1·3156 gram.
	Weight of AgCl	„	3·6907 grams.
II.	Weight of $POCl_3$	„	1·4364 gram.
	Weight of AgCl	„	4·1064 grams.

	Calculated.	Found.	
		I.	II.
Chlorine	69·36 per cent.	69·37	69·39

Three determinations of specific gravity made with different bottles gave the following numbers:—

I.	1·71185
II.	1·71189
III.	1·71182
Mean	1·71185 at 0°

compared with water at same temperature; compared with water at 4° the specific gravity is 1·71163.

The rate of expansion of phosphoryl trichloride from 0° to its boiling-point may be accurately represented by the expression

$$V=1+0{\cdot}001\,064\,309t+0{\cdot}000\,001\,126\,66t^2 \\ +0{\cdot}000\,000\,005\,299t^3.$$

By means of this formula the following Table, showing the true volume of phosphoryl trichloride at every 10° between 0° and 110°, has been calculated:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		70	108184	1278
10	101076	1076	80	109507	1323
20	102178	1102	90	110878	1371
30	103309	1131	100	112300	1422
40	104471	1162	110	113776	1476
50	105669	1198			
60	106906	1237	107·23	1·133615	

The specific gravity of phosphoryl trichloride at 107°·23 is 1·50987; hence its specific volume$=\frac{153\cdot38}{1\cdot50987}=101\cdot58$.

The specific gravity of this compound at 10°, at 51°, and at its boiling-point has already been determined by H. L. Buff*. The results of his observations, compared with mine for the above temperatures, are given below; the specific gravities are compared with water at 0°.

	10°.	51°.	Boiling-point.
Buff........	1·6937	1·6494 (? 1·6194)	1·5090 (110°)
Thorpe	1·6936	1·6181	1·51008 (107°·23)

The specific volume of phosphoryl trichloride, calculated from Buff's numbers, is 101·6.

II. *Vanadyl Trichloride.*

This compound was prepared by heating vanadium trioxide, obtained by reducing the pentoxide by means of hydrogen gas, in a stream of dry chlorine. I am indebted to Dr. Roscoe for the pentoxide; it was a portion of the sample employed by him in determining the atomic weight of vanadium, and had been prepared with great care; it was beautifully crystalline and of a magnificent ruby-red colour†. In order to free the vanadyl trichloride from dissolved chlorine, it was maintained at a temperature near its boiling-point for a couple of hours in a current of dry carbon dioxide. The chloride was distilled into the flask in which its boiling-point was to be determined. Therm. Casella C. The liquid commenced to boil at 127°·2; the column rapidly rose to 127°·3, at which point it remained constant. $n=10°$, $t'=30°$. Bar. 764·5 millims. Correction for scale-error on thermometer −0°·15. Corrected boiling-point 127°·29. Corrected and reduced boiling-point 127°·19.

The results obtained with the dilatometer may be represented by the formula

$$V=1+0\cdot000\,965\,236t+0\cdot000\,000\,898\,26t^2 \\ +0\cdot000\,000\,003\,191\,63t^3,$$

by means of which is calculated the following Table, showing the true volumes of vanadyl trichloride for every 10° between 0° and 130°:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		80	108460	1154
10	100975	975	90	109647	1187
20	101969	994	100	110870	1223
30	102985	1016	110	112129	1259
40	104025	1040	120	113428	1299
50	105091	1066	130	114767	1339
60	106184	1093			
70	107306	1122	127·19	1·143867	

---

* Ann. Chem. Pharm. Suppl. vol. iv. p. 184.

† Phil. Trans. 1867, p. 1.

The mean of three experiments gives the specific gravity of vanadyl trichloride at 0°, compared with water at 4°, as 1·86527. Roscoe found 126°·7 for the boiling-point of this compound, and for its specific gravity

1·841 at 14°·5	reduced	1·8655 at 0°
1·836 at 17°·5	„	1·8653 „
1·828 at 24°	„	1·8665 „

The reduced sp. gr. (S_0) in this and the following cases has been calculated by means of the expression

$$S_0 = S_t \frac{V'}{V},$$

in which

S_t = the sp. gr. at the higher temperature t,

V' = the volume of the liquid at t, obtained by the interpolation formula.

V = volume of the water at t (vol. at 4° = 1), obtained from Rossetti's Tables[*].

The indications of the dilatometer have been controlled by determining the degree of expansion suffered by the vanadyl trichloride on being heated in the specific-gravity bottle from 0° to near 100°, *i. e.* in the steam from boiling water. The details of the experiments are as follows:—

Experiment I.	Weight of $VOCl_3$ at 10° *in vacuo*	7·15114 grams.
	Weight of $VOCl_3$ *in vacuo* after having been heated to 100°·37. Bar. 770·3 millims.	6·46541 „
	Expansion of glass for 1°......	·00002633

Hence 10,000 vols. at 0° become at 100°·37—

Observed	11090
Calculated from formula	11091

Experiment II.	Weight of $VOCl_3$ at 0° *in vacuo*	7·15156 grams.
	Weight of $VOCl_3$ *in vacuo* after having been heated to 100°·10. Bar. 762·9 millims.........	6·46736 „
	Expansion of glass for 1°	·00002633

Hence 10,000 vols. at 0° become at 100°·10—

Observed	11087
Calculated from formula	11088

The agreement between the results is satisfactory. The control is important, since it might be supposed, from Matthiessen's criticism of Kopp's observations on the expansion of water, that the dilatometric method of determining the expansion of liquids tends to give low results[*].

---

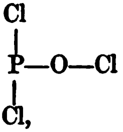
[*] Ann. de Chim. et de Phys. x. 1867, xvii. 1869. Mean results of the observations of Kopp, Pierre, Despretz, Hasgen, Matthiessen, Weidner, Kremers, and Rossetti.

The specific gravity of vanadyl trichloride at 127°·19 is 1·63067; hence its specific volume is $\frac{173·73†}{1·63067}=106·54$.

It is thus evident that the specific volumes of vanadyl and phosphoryl trichlorides are not equal; the compound with the higher molecular weight has the greater specific volume.

In the communication on the chlorides of phosphorus already referred to, it is shown that if we assume, as appears in the highest degree probable, that there is a relation between the manner in which the oxygen atoms in a compound are held in union and their specific volume, it follows that the oxygen atom in $POCl_3$ possesses the smaller of the two values 12·2 and 7·8 assigned by Kopp to oxygen, and accordingly that this atom is attached to the phosphorus by only one combining unit.

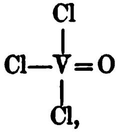
Thus



$$\overset{\overset{\text{Cl}}{|}}{\underset{\underset{\text{Cl,}}{|}}{\text{P}}}\text{—O—Cl}$$

showing that the phosphorus atom in phosphoryl trichloride possesses the same atomic value as in phosphorus trichloride.

As the difference between the two values for the volume of oxygen, viz. 12·2 − 7·8 = 4·4, is but little less than that between the specific volumes of $VOCl_3$ and $POCl_3$, viz. 106·54 — 101·58 = 4·96, it is possible that the difference in the specific volumes of the two liquids may be due to the different manner in which the oxygen atoms are united to the vanadium and phosphorus atoms; for, if V be regarded as a pentad, $VOCl_3$ must be written



$$\text{Cl—}\overset{\overset{\text{Cl}}{|}}{\underset{\underset{\text{Cl,}}{|}}{\text{V}}}\text{=O}$$

the oxygen atom having the value 12·2. Assuming Kopp's value for Cl, viz. 22·8, this would leave for P and V nearly the same specific volume, viz.

P .... 25·4
V .... 25·9

From the uncertainty respecting the particular volume to be assigned to the oxygen atom in vanadyl trichloride, our knowledge of the specific volumes of $VOCl_3$ and $POCl_3$ gives us little aid towards solving the question whether the several members of a family of elements have identical specific volumes.

---

[*] Phil. Trans. 1866.

[†] V=51·35, Roscoe; Cl=35·46, Stas.

With a view to obtain further evidence, I have redetermined with special care the boiling-points, specific gravities, and rates of expansion of the tetrachlorides of silicon, titanium, and tin.

The atomic weights of Si and Ti and of P and V show about the same gradational difference:—

Si........	28·10	P........	31·00
Ti........	50·00	V........	51·35

And since the tetrachlorides are free from oxygen, the uncertainty arising from the variable specific volume of that element is eliminated. I have also compared the specific volumes of the trichlorides of phosphorus, arsenic, and antimony, making use of Kopp's determination in the case of the last-named compound. We thus obtain material for the discussion of the question from analogous derivatives of two well-defined groups of elements, viz.:—

Si........	28·10	P........	31·00
Ti........	50·00	V........	51·35
		As	75·15
Sn	118·10	Sn	122·30

III. *Silicon Tetrachloride.*

This compound was prepared in the ordinary way by heating a mixture of pure silica and lampblack (previously ignited in chlorine) in a current of dry chlorine gas. The product was distilled repeatedly over sodium. It boiled constantly between 58° and 58°·3, the greater portion coming over at 58°·2.

Corrected boiling-point 57°·95. Bar. 765·35 millims. Corrected and reduced boiling-point 57°·57.

Its specific gravity at 0°, compared with water at 4°, is 1·52408. Other observations on record are:—

	Boiling-point. °	Barom. millim.	Sp. gr.	Compared with water at 4°.
Pierre[*]	59·0	760·1	1·52371 at 0°	1·52371 at 0°
Reguault[†]..	56·81	760·0	——	——
Haagen[‡] ..	58·0	756·0	1·4878 at 20°	1·52644 „
? Mendelejeff	——	——	1·50068 at 10°·98	1·52266 „
Mendelejeff[§]	——	——	1·4928 at 15°	1·52230 „

Two series of observations of the expansion of silicon tetrachloride were made. The results of the first series may be accurately represented by the formula

$$V = 1 + 0{\cdot}001\,337\,14t + 0{\cdot}000\,002\,618\,01t^2 + 0{\cdot}000\,000\,003\,907\,62t^3. \quad . \quad . \quad . \quad \text{(I.)}$$

---

[*] Ann. de Chim. et de Phys. xx. [3], p. 26.

[†] From vapour-tension observations.

[‡] Pogg. Ann. cxxxi. p. 117.

[§] Jahresbericht, xiii. p. 7.

The second series of observations may with equal accuracy be represented by the expression

$$V=1+0{\cdot}001\,324\,75t+0{\cdot}000\,003\,001\,54t^2+0{\cdot}000\,000\,000\,405\,511t^3 \quad \text{. . . (II.)}$$

The mean formula is

$$V=1+0{\cdot}001\,330\,946t+0{\cdot}000\,002\,809\,78t^2+0{\cdot}000\,000\,002\,156\,57t^3, \quad \text{. . . (III.)}$$

by the aid of which the following Table, showing the true volumes of silicon tetrachloride for every 5° between 0° and 60°, has been calculated:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		40	105787	775
5	100673	673	45	106578	791
10	101359	686	50	107384	806
15	102060	701	55	108206	822
20	102776	716	60	109044	838
25	103506	730			
30	104252	746	57·57	1·086346	
35	105012	760			

The specific gravity at the boiling-point is 1·40295, and the specific volume $=\frac{169{\cdot}94^*}{1{\cdot}40295}=121{\cdot}13$.

Pierre has given the following expression for the expansion of this liquid[†]:—

$$V=1+0{\cdot}001\,294\,119\,069t+{\cdot}000\,002\,184\,143\,631t^2+{\cdot}000\,000\,040\,864\,220t^3.$$

This formula represents a curve slightly differing in character from that afforded by my observations, as is evident from the following comparison. The temperature in this and the following comparisons is given in degrees of the mercurial thermometer.

	10°	20°	30°	40°	50°
Pierre	1·01320	1·02708	1·04189	1·05804	1·07527
Thorpe	1·01349	1·02757	1·04226	1·05756	1·07352

The specific volume of silicon tetrachloride, calculated from Pierre's results, is $\frac{169{\cdot}94}{1{\cdot}39502}=121{\cdot}82$.

IV. *Titanium Tetrachloride.*

I am indebted to Mr. Phillips Bedson, B.Sc., of Owens College, for a liberal supply of a pure specimen of this liquid. On distillation it commenced to boil at 135°·8; the column rapidly rose to 135°·9, at which

---

[*] $Si=28{\cdot}10$, Dumas; $Cl=35{\cdot}46$, Stas.

[†] *Loc. cit.*

point the liquid boiled constantly. $t=135^{\circ}{\cdot}9$, $n=19^{\circ}{\cdot}9$, $t'=24^{\circ}{\cdot}5$. Bar. 752·6 millims. Corrected boiling-point 136°·03. Corrected and reduced boiling-point 136°·41.

Its specific gravity at 0°, compared with water at 4°, was found to be 1·76041. According to Pierre titanium chloride boils at 136° under a pressure of 762·3 millims., and has a specific gravity of 1·76088 at 0° compared with water at 4°*.

Observations with the dilatometer have led to the formula

$$V=1+0{\cdot}000\,982\,612t+0{\cdot}000\,000\,505\,528t^2 \\ +0{\cdot}000\,000\,005\,130\,52t^3,$$

by means of which the following Table has been calculated:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		90	109627	1180
10	100988	988	100	110845	1218
20	101990	1002	110	112103	1258
30	103007	1017	120	113406	1303
40	104044	1037	130	114756	1350
50	105104	1060	140	116155	1399
60	106189	1085			
70	107302	1113	136·41	1·156467	
80	108447	1145			

The specific gravity of the liquid at 136°·41 is 1·52223, and the specific volume $=\frac{191{\cdot}84\dagger}{1{\cdot}52223}=126{\cdot}025$.

According to Pierre the expansion of titanium tetrachloride may be represented by the formula‡

$$V=1+0{\cdot}000\,942\,569\,004t+0{\cdot}000\,001\,345\,791\,937t^2 \\ +0{\cdot}000\,000\,000\,888\,044t^3,$$

which gives results agreeing well with those afforded by my observations, as the following comparison shows:—

	30°	60°	90°	120°
Pierre........	1·02951	1·06159	1·09638	1·13402
Thorpe	1·02989	1·06169	1·09621	1·13414

The specific volume of titanium chloride, calculated from Pierre's results, is $\frac{191{\cdot}84}{1{\cdot}52415}=125{\cdot}867$.

V. *Tin Tetrachloride.*

Prepared by heating pure tin in a current of dry chlorine and expelling the dissolved gas by repeated distillation in a stream of dry carbon dioxide. The liquid commenced to boil at 113°·4; the column quickly rose to 113°·5, and then slowly to 113°·55, between which points nearly the entire amount passed over. $t=113^\circ{\cdot}55$, $n=6^\circ{\cdot}55$, $t'=24^\circ{\cdot}5$. Bar. 750·8 millims. Corrected boiling-point 113°·50. Corrected and reduced boiling-point 113°·89.

---

* *Loc. cit.* p. 21.

† Ti=50·00, Pierre; Cl=35·46, Stas.

‡ *Loc. cit.* p. 20.

Its specific gravity at 0°, compared with water at 4°, was found to be 2·27875. Other observers have found:—

	Boiling-point. °	Bar. millim.		Sp. gr. compared with water at 4° C.
Pierre*	115·4	753·1	....	2·26712
Dumas†	120	767		——
Andrews‡	112·5	752		——
Haagen§......	112·0	754·9	2·2328 at 20°=	2·28137

Two independent series of observations on the rate of expansion of the tin tetrachloride were made. The first series has afforded the formula

$$V=1+0{\cdot}001\,161\,138t+0{\cdot}000\,000\,641\,935t^2+0{\cdot}000\,000\,007\,730\,07t^3 \quad . \; . \; . \; (I.)$$

The formula given by the second series is

$$V=1+0{\cdot}001\,159\,962t+0{\cdot}000\,000\,650\,399t^2+0{\cdot}000\,000\,007\,724\,12t^3. \quad . \; . \; (II.)$$

The mean formula is

$$V=1+0{\cdot}001\,160\,55t+0{\cdot}000\,000\,646\,167t^2+0{\cdot}000\,000\,007\,727\,1t^3, \quad . \; . \; (III.)$$

by means of which the following Table, showing the volume of tin tetrachloride at every 10° between 0° and 115°, has been calculated:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		80	110094	1388
10	101168	1168	90	111532	1438
20	102353	1185	100	113024	1492
30	103561	1208	110	114576	1552
40	104795	1234	115	115376	800
50	106061	1266			
60	107363	1302	113·89	1·151971	
70	108706	1343			

The specific gravity at 113°·89 is 1·97813; hence the specific volume is

$$\frac{259{\cdot}94\,\|}{1{\cdot}97813}=131{\cdot}407.$$

---

* *Loc. cit.* p. 19.

† Clarke's Nat. Constants.

‡ Clarke's Nat. Constants.

§ Pogg. Ann. vol. cxxxi. p. 117.

‖ Sn=118·10, Dumas; Cl=35·46, Stas.

Pierre represents the expansion of this liquid by the equation[*]:—

$$V = 1 + 0{\cdot}001\,132\,800\,769t + 0{\cdot}000\,000\,911\,710\,706t^2 + 0{\cdot}000\,000\,007\,579\,789t^3,$$

which gives results somewhat lower than those afforded by formula III.

	20°.	40°.	60°.	80°.	100°.
Pierre....	1·02308	1·04726	1·07289	1·10034	1·12998
Thorpe ..	1·02347	1·04771	1·07340	1·10080	1·13024

The specific volume of tin tetrachloride, calculated from Pierre's observations, is $\frac{259{\cdot}94}{1{\cdot}96373} = 132{\cdot}371$.

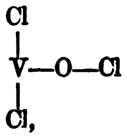
The results of the determinations of the specific volumes of the tetrachlorides of silicon, titanium, and tin, liquids of analogous constitution and all derivatives of the tetrad group of elements, serve to establish the conclusion, indicated by the difference in the specific volumes of phosphoryl and vanadyl trichlorides, that the specific volumes of the several members of a family of elements are not identical, but that the values increase with the increase of the atomic weight of the members.

	Molecular weight.	Specific volume.
$SiCl_4$	169·94	121·13
$TiCl_4$	191·84	126·03
$SnCl_4$	259·94	131·41

It is also noteworthy that the difference between the specific volumes of tin and titanium tetrachlorides is almost the same as the difference between the specific volumes of vanadyl and phosphoryl trichlorides; it has already been remarked that the difference between the atomic weights of vanadium and phosphorus is nearly the same as that between the atomic weights of titanium and silicon.

	Mol. weight.	Diff.	Spec. vol.	Diff.
$POCl_3$	153·38	20·35	101·58	4·96
$VOCl_3$	173·73		106·54	
$SiCl_4$.	169·94	21·90	121·13	4·90
$TiCl_4$	191·84		126·03	

It would seem from this that the constitution of vanadyl trichloride is similar to that of the phosphoryl compound, and must therefore be expressed by the formula



$$\begin{array}{l} Cl \\ | \\ V—O—Cl \\ | \\ Cl, \end{array}$$

in which V appears as a triad, the oxygen atom having the same specific volume as in phosphoryl trichloride. On the other hand, the order of the divergences shown by P, As, and Sb (*vide infrà*), would appear to indicate that V may be pentad in this compound, whence O would have the volume 12·2.

---

[*] *Loc. cit.* p. 20.

Comparison of the specific volumes of PCl_3, $AsCl_3$, and $SbCl_3$:—

VI. *Phosphorus Trichloride.*

I prepared this compound by heating purified amorphous phosphorus in dry chlorine gas. The reaction is very regular, and large quantities of the liquid may be thus obtained with great ease and rapidity. The product was digested with ordinary phosphorus for some weeks to remove the last trace of free chlorine. On distillation the liquid commenced to boil at 76°·05, and all came over below 76°·25, the most constant point appearing to be at 76°·15. $n=18°·2$, $t'=26°·0$. Bar. 768·2 millims. Corrected and reduced boiling-point 75°·95. Two determinations of specific gravity gave—

I.	1·61290
II.	1·61299
Mean	1·61294 at 0°

compared with water at 0°; compared with water at 4° its specific gravity is 1·61275.

Other observers have found for the boiling-point and specific gravity of phosphorus trichloride :—

	B.P. °	Bar. millim.		Sp. gr. at 0° compared with water at 4°.
Pierre[*]	78·34	751·5	....	1·61616
H. L. Buff[†] ..	76·0	760·0	1·61191 at 0°[‡]	1·61170
Haagen[§]	76·0	745·9	1·5774 at 20°	1·61165

The observations with the dilatometer have led to the formula

$$V=1+0·001\,139\,37t+0·000\,001\,668\,07t^2 \\ +0·000\,000\,004\,012t^3,$$

by means of which the following Table, showing the true volume of phosphorus trichloride at every 10° between 0° and 80°, has been calculated :—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		50	106164	1314
10	101156	1156	60	107523	1359
20	102349	1193	70	108931	1408
30	103579	1230	80	110388	1457
40	104850	1271			
			75·90	1·09784	

---

[*] *Loc. cit.* p. 9.

[†] Ann. der Chem. und Pharm. Suppl. vol. iv. p. 184.

[‡] Mean of 1·61253 and 1·61128, compared with water at 0°.

[§] *Loc. cit.*

The specific gravity at 75°·90 is 1·46900, and accordingly the specific volume is $\frac{137·38}{1·4690}=93·52$.

Pierre has found that the expansion of phosphorus chloride may be represented by the formula*

$$V=1+0·001\,128\,618\,932t+0·000\,000\,872\,880\,045t^2 \\ +0·000\,000\,017\,923\,565t^3,$$

which gives results agreeing fairly well with those calculated by means of the expression deduced from my observations.

	10°.	30°.	50°.	70°.
Pierre	1·01139	1·03513	1·06085	1·08943
Thorpe	1·01147	1·03557	1·06138	1·08911

The specific gravity of phosphorus trichloride at various temperatures has also been determined by Buff†. The results of the several observations are:—

	Sp. gr. at B.P.	B.P.	Spec. vol.
Buff........	1·47102	76·0	93·39
Pierre	1·46601	78·34	93·71
Thorpe	1·46900	75·90	93·52
		Mean	93·54

VII. *Arsenic Trichloride.*

This compound was obtained by heating arsenic trioxide in a current of dry chlorine. It was distilled upwards in a current of dry carbon dioxide for some time in order to expel the excess of chlorine. Care is necessary to obtain a perfectly clear product; the least trace of moisture renders the liquid turbid from the formation of the insoluble oxychloride, AsClO. On distillation the liquid commenced to boil at 129°·23, and all came over below 129°·33, the greater portion boiling at 129°·30. $n=16°$, $t'=15°·5$. Bar. 733·4 millims. Corrected and reduced boiling-point 130°·21.

Its specific gravity at 8°·08, compared with water at the same temperature, was 2·18761; compared with water at 4° its specific gravity is found to be 2·20500.

Other observers have given for the boiling-point and specific gravity of arsenic trichloride—

	B.P.	Bar. millim.		Sp. gr. compared with water at 4°.
Pierre	133·81	765·9	....	2·20495 at 0°
Haagen	128·0	754·0	2·1668 at 20°	2·20671 ,,

---

* *Loc. cit.* p. 10. The third term is erroneously printed 0·0000179 ....

† *Loc. cit.*

The observations with the dilatometer have afforded the formula

$$V = 1 + 0{\cdot}000\,991\,338\,5t + 0{\cdot}000\,000\,849\,14t^2 + 0{\cdot}000\,000\,002\,755\,08t^3,$$

by the aid of which the following Table is obtained; it shows the volume of arsenic trichloride at every 10° between 0° and 130°, the volume at 0° being taken as 100,000.

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		80	108615	1165
10	101000	1000	90	109811	1196
20	102019	1019	100	111038	1227
30	103058	1039	110	112299	1261
40	104119	1061	120	113595	1296
50	105203	1084	130	114928	1333
60	106313	1110			
70	107450	1137	130·21	1·14956	

The specific gravity of arsenic trichloride at 130°·21 is 1·91812; hence its specific volume is $\frac{181{\cdot}53^*}{1{\cdot}91812} = 94{\cdot}64$.

Pierre represents the expansion of this liquid by the expression†

$$V = 1 + 0{\cdot}000\,979\,072\,746t + 0{\cdot}000\,000\,966\,948\,2t^2 + 0{\cdot}000\,000\,001\,777\,204t^3,$$

which gives results uniformly lower than those afforded by my observations:—

	30°.	60°.	90°.	120°.
Pierre......	1·03029	1·06261	1·09724	1·13448
Thorpe	1·03040	1·06295	1·09805	1·13602

The specific volume of arsenic trichloride deduced from Pierre's numbers is $\frac{181{\cdot}53}{1{\cdot}91304} = 94{\cdot}891$.

VIII. *Antimony Trichloride.*

The rate of expansion of this compound has been determined by Kopp, who has given the following formula to express his observations‡:—

$$V = 1 + 0{\cdot}000\,805\,4\delta + 0{\cdot}000\,010\,33\delta^2,$$

in which δ = the number of degrees above the melting-point of the body, 73°·2 (Kopp). According to Kopp antimony trichloride boils at 223°, under a pressure of 747·7 millims. Reduced boiling-point 223°·5. Its specific gravity at 73°·2, compared with water at 4°, is 2·6753; at 223°·5 it is 2·3377. Accordingly its specific volume $= \frac{228{\cdot}68\,\S}{2{\cdot}3377} = 97{\cdot}82$.

---

[*] As = 75·15, Kessler; Cl = 35·46, Stas. [†] *Loc. cit.*

[‡] Ann. der Chem. und Pharm. vol. xcv. p. 350.

[§] Sb = 122·3, Kessler, Dexter; Cl = 35·46, Stas.

The numbers representing the specific volumes of the trichlorides of phosphorus, arsenic, and antimony exhibit a gradational order similar to that shown by the volumes of the tetrachlorides of silicon, titanium, and tin, and also by the specific volumes of phosphoryl and vanadyl trichlorides:—

	Mol. weight.	Spec. vol.
PCl_3	137·38	93·54
$AsCl_3$	181·53	94·64
$SbCl_3$	228·68	97·82

although the differences are much less than in the cases of the two latter groups. I intend to return to the question in subsequent communications.

II. "Researches upon the Specific Volumes of Liquids." By T. E. Thorpe, Ph.D., F.R.S.E., Professor of Chemistry in the Yorkshire College of Science, Leeds. Communicated by Prof. A. W. Williamson, For. Sec. R.S. Received February 9, 1876.

III. *On the Specific Volumes of Bromine and Iodine Monochloride, and of Ethene Bromide and Ethene Chloriodide.*

The molecular weight of bromine is, as is well known, nearly equal to the arithmetic mean of the molecular weights of chlorine and iodine: hence the molecular weights of bromine and of iodine monochloride (I Cl) are nearly identical. These substances closely resemble each other in physical properties. Both are dark-red liquids about three times heavier than water. Bromine boils at about 59°·5, and solidifies at −24°·5; iodine monochloride melts at +24°·5, and boils at 101°: the interval between the boiling- and melting-points of the two compounds is approximately equal.

It appeared to me of interest to determine (1) if the specific volumes of these liquids exhibit a relation similar to that which is shown by their molecular weights, and (2) if the relation in their specific volumes is preserved in analogous combinations of the two bodies. I have accordingly determined the specific gravities, boiling-points, and rates of expansion of bromine and iodine monochloride, and of the compounds which these substances form by their union with ethene, C_2H_4. Th observations will also serve to determine if bromine and iodine mono chloride preserve, when in combination, the volumes which they posses in the free state.

I. *Bromine.*

About a kilogramme of the purest commercial bromine, dehydrate by agitation with pure and strong sulphuric acid, was carefully distilled and the fraction boiling at about 60°, which amounted to about tw thirds of the whole, was collected separately. A portion of the distillate was treated with milk of lime and ammonia, and the resulting calcium bromide was tested for iodine in the usual manner, but not a trace was detected. The remainder of the bromine was digested with powdered potassium bromide for several months, again distilled and agitated with phosphoric pentoxide to remove the last traces of moisture. The purified bromine boiled constantly between 59°·6 and 59°·7. $n=0$, $t'=0$. Barometer (corrected and reduced) 765·2 millims. Reduced and corrected boiling-point 59°·45. In degrees of air-thermometer 59°·27.

A determination of the specific gravity of the bromine gave 3·15787 at 9°·17, compared with water at the same temperature. Its specific gravity at 0°, compared with water at 4°, is 3·18828.

Other observers have found for the specific gravity and boiling-point of bromine:—

	Boiling-point.	Specific gravity.
	millims.	
Pierre	63° at 760·02	3·18718 at 0°.
Andrews	58 „ ?	
Bolas and Groves	59·6 „ 751	

The observations of Balard and Löwig are not given, as they were evidently made with bromine containing large quantities of chlorine.

The observations with the dilatometer have led to the following formula as expressing the expansion of bromine between 0° and its boiling-point:—

$$V=1+0{\cdot}001\,062\,18t+0{\cdot}000\,001\,877\,141t^2-0{\cdot}000\,000\,003\,085\,38t^3.$$

By the aid of this formula the following Table has been calculated. It shows the true volume of bromine at every 5° between 0° and 60°, the volume at 0° being taken as 100,000.

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		40	104529	595
5	100536	536	45	105132	603
10	101081	545	50	105742	610
15	101635	554	55	106359	617
20	102197	562	60	106983	624
25	102768	571			
30	103347	579	59°·27	1·069111	
35	103934	587			

The specific gravity of bromine at its boiling-point is 2·98218, and its specific volume $=\dfrac{2\times 79{\cdot}95^*}{2{\cdot}98218}=53{\cdot}618$.

---

* Br = 79·95 (Stas).

The rate of expansion of bromine has already been determined by Pierre, who has given the following expression to represent the results of his observations[*]:—

$$V=1+0{\cdot}001\,038\,186\,255t + 0{\cdot}000\,001\,711\,380\,853t^2 + 0{\cdot}000\,000\,005\,447\,118t^3.$$

This formula gives numbers agreeing fairly well with those afforded by the expression deduced from my determinations, as the following comparison shows (the temperatures are given in degrees of the mercurial thermometer):—

	15°	30°	45°	60°
Pierre........	1·01608	1·03273	1·05068	1·06963
Thorpe	1·01624	1·03326	1·05108	1·06960

Pierre was undoubtedly one of the first to obtain bromine in a state approaching to purity; but it seems probable, in spite of the care which was evidently taken in its preparation, that the sample employed by him in his determination of its rate of expansion was not perfectly free from water. This is indicated by the order of the divergence between the results of our various observations; and the supposition would seem to be confirmed by the high solidifying-point, viz. −7°·5 to −8°, which he observed. Baumhauer has shown that the true freezing-point of bromine is at −24°·5[†]. Pierre sought to dry his bromine by digestion with calcium chloride. According to Stas, calcium bromide (which, as a desiccating agent is not inferior to the chloride) is incapable of removing the last traces of water from bromine[‡].

The specific volume of bromine, calculated from Pierre's numbers, is

$$\frac{159{\cdot}90}{2{\cdot}96881}=53{\cdot}859.$$

II. *Iodine Monochloride.*

Prepared by heating an intimate mixture of iodine and potassium chlorate, and distilling the product from powdered potassium chlorate,

$$I_2+3KClO_3=KClO_4+KIO_3+KCl+O_2+ICl.$$

The product was repeatedly distilled in order to break up the last traces of the yellow iodine trichloride which is always formed in slight quantity in the preparation. The liquid ultimately boiled constantly between 99°·7 and 100°·7; n=40°, t'=75°. Corrected and reduced barometer 744·3 millims. Corrected and reduced boiling-point 101°·3.

In order to establish its purity the iodine monochloride was analyzed by breaking bulbs containing weighed portions of the liquid under dilute sulphurous acid solution, precipitating the hydrochloric and hydriodic acids by silver nitrate, and digesting the mixed salts with strong nitric acid.

---

[*] Ann. de Chim. et de Phys. [3] 20.

[†] Deutsch. Ch. Ges. Ber. 1871, p. 927.

[‡] Stas, Nouvelles Recherches sur les Lois des Prop. Chem. &c. Aronstein's German translation, p. 179.

I.	Amount of I Cl taken	1·2482 gram.
II.	„ „ „	0·5668 „
I.	Silver salts obtained	2·9095 grams.
II.	„ „ „	1·3223 gram.

From these data, using Stas's numbers for the atomic weights of chlorine, iodine, and silver ($Cl=35·46, I=126·85, Ag=107·93$), we get, by means of the equation

$$W = \frac{I+Ag}{I}x + \frac{Cl+Ag}{Cl}y$$

(in which W = the weight of mixed silver salts, and x and y respectively the amount of iodine and chlorine contained therein), the following results expressed in percentages :—

	I.	II.	Calculated.
Chlorine	21·86	21·98	21·85
Iodine	78·14	78·02	78·15
	100·00	100·00	100·00

Iodine monochloride, as a liquid, bears a marked resemblance to bromine. Although when solidified it melts at a temperature as high as 24°·2 (according to my observations), it not unfrequently remains liquid for many weeks after distillation, and may be cooled to below 0° without congealing. In a freezing-mixture of ice and salt it readily solidifies to a dark reddish-brown crystalline mass. Long-continued shaking at ordinary temperatures occasionally brings about its solidification. A quantity of iodine monochloride which had been liquid for months crystallized in long prisms when subjected to the vibration of a railway-carriage. Mr. J. B. Hannay has already published a number of curious observations on the solidification of this compound *.

The specific gravity of iodine monochloride at 17°·95 is 3·12988, compared with water at 4°; at 0° its specific gravity is 3·18223, compared with water at 4°.

Other observers have found for the melting- and boiling-points of this compound :—

	Boiling-point.	Melting-point.
Schützenberger	100°–102°	30°
Trapp	....	25°
Hannay	100°–102°	24°·7

Observations with the dilatometer have led me to the following formula

---

* Journ. Chem. Soc. 1873, p. 815.

as expressing the expansion of iodine monochloride between 0° and its boiling-point:—

$$V = 1 + 0{\cdot}000\,915\,896\,6t + {\cdot}000\,000\,832\,957\,6t^2 + 000\,000\,002\,750\,05t^3,$$

by means of which the following Table has been calculated:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		55	105335	513
5	100460	460	60	105855	520
10	100925	465	65	106381	526
15	101394	469	70	106914	533
20	101867	473	75	107454	540
25	102346	479	80	108001	547
30	102830	484	85	108556	555
35	103320	490	90	109118	562
40	103815	495	100		
45	104315	500			
50	104822	507	101·3	1·104187	

The specific gravity at 101·3 is 2·88196; hence the specific volume of iodine monochloride $= \frac{162{\cdot}31}{2{\cdot}88196} = 56{\cdot}319$.

In the paper already referred to, Mr. Hannay has given the results of a number of observations on the specific gravity of this compound at various temperatures. I am unable to compare his numbers with my own, as the temperatures to which his specific gravities are referred are not given; but the conclusion which Mr. Hannay draws from his observations, "that iodine monochloride expands equally for equal increments of temperature, even near its boiling-point," is obviously erroneous.

III. *Ethene Dibromide*, $C_2H_4Br_2$.

This compound was prepared from well-washed ethene and bromine by means of the arrangement described by Hofmann. The product, after having been dried by phosphorus pentoxide, boiled completely between 130°·1 and 130°·8, the greater portion coming over between 130°·6 and 130°·7; $n=55°$, $t'=110°$. Barometer corrected and reduced 766·6 millims. Corrected and reduced boiling-point 131°·36. In air-thermometer degrees 131°·45.

The statements on record respecting the solidifying-point of this compound are extremely discordant; they vary from −12° or −15° to +13°·1. By careful trial I found that ethene dibromide solidifies at +9°·2, which is almost identical with the number given by Regnault, viz. 9°·53.

The specific gravity of ethene dibromide is 2·19011 at 10°·89, compared with water at 4°. On the supposition that the liquid contracts regularly below its ordinary solidifying-point, its specific gravity at 0° is 2·21324, compared with water at 4°. Other observers have found for the boiling- and freezing-points and specific gravity of this compound:—

	Boiling-point.		Melting-point.	Specific gravity.
	°		°	°
Regnault ..	131·6	at 760 mm.	9·53	
Pierre	132·6	„ 756·9	13·1	2·16292 at 20·79
Haagen ..	131·6	„ ?	..	2·1827 „ 20
Cahours ..	130	„ ?	0	
Reboul	..		..	2·198 „ 10

The results of the observations with the dilatometer have afforded me the following formula, which expresses with sufficient exactitude the rate of expansion of this liquid from 0° to its boiling-point:—

$$V = 1 + 0{\cdot}000\,952\,845t + 0{\cdot}000\,000\,683\,455t^2 + 0{\cdot}000\,000\,00\,394\,763t^3.$$

The following Table is calculated by means of this expression; it shows the true volumes of ethene dibromide at every 5° between 0° and 135°:—

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		75	107697	557
5	100478	478	80	108262	565
10	100960	482	85	108835	573
15	101446	486	90	109417	582
20	101936	490	95	110007	590
25	102431	495	100	110607	600
30	102931	500	105	111215	608
35	103436	505	110	111834	619
40	103946	510	115	112462	628
45	104462	516	120	113101	639
50	104984	522	125	113750	649
55	105513	529	130	114409	659
60	106049	536	135	115080	671
65	106591	542			
70	107140	549	131·45	1·14602	

The specific gravity of ethene dibromide at its boiling-point is 1·93124, and its specific volume $= \frac{187{\cdot}90}{1{\cdot}93124} = 97{\cdot}295$.

Pierre, who has already determined the expansion of this liquid, found that a single expression of the form

$$V = 1 + at + bt^2 + ct^3$$

would not express the results of his observations with sufficient accuracy.

He also selected the volume at 20°·09, the lowest temperature at which he made an observation, as the unit of volume, on the ground that at lower temperatures, particularly in the neighbourhood of its freezing-point, the dilatation of the liquid might be irregular, a supposition which is not confirmed by my observations. He accordingly calculated two expressions of the form *

$$V = 1 + a\theta + b\theta^2 + c\theta^3,$$

in which $\theta = t - 20°{\cdot}09$.

From 20°·09 to 100°·16 the expansion may be expressed by the formula

$$V = 1 + 0{\cdot}000\,952\,696\,19\theta + 0{\cdot}000\,001\,316\,506{\cdot}858\theta^2 + 0{\cdot}000\,000\,001\,062\,687\theta^3;$$

and from 100°·16 to 132°·6 by the formula

$$V = 1 + 0{\cdot}001\,016\,765\,988\theta + 0{\cdot}000\,000\,102\,231\,770\theta^2 + 0{\cdot}000\,000\,008\,788\,007\theta^3.$$

These formulæ give results differing but little from those afforded by the expression deduced from my observations, as is evident from the following comparison (the temperatures are given in degrees of the mercurial thermometer):—

	20°·09	50°·09	80°·09	110°·09	130°·09
Pierre....	1·00000	1·02980	1·06213	1·09709	1·12238
Thorpe ..	1·00000	1·03003	1·06230	1·09750	1·12284

The specific volume of ethene dibromide, calculated from the numbers given by Pierre, on the assumption that the specific gravity of the liquid at 20°·79, viz. 2·16292, as given by him, is compared with water at 4° (the temperature of comparison is not stated, but it is probably that which is assumed), is 97·7.

IV. *Ethene Chloriodide*, C_2H_4ICl.

This remarkable compound was first prepared by Maxwell Simpson. To obtain it, finely powdered iodine is suspended in about three times its weight of water, and chlorine is passed into the liquid (which should be kept cool and constantly agitated) until the iodine has nearly disappeared; the liquid is decanted after standing, and a stream of ethene, washed by passing through soda solution, is led into it until both the liquid and the oil which gradually separates out are decolorized. The compound, after washing and drying, is found to boil nearly constantly. When first prepared it is colourless; but on exposure to light it gradually becomes red from the separation of a trace of iodine †.

In order, if possible, to avoid the use of water in the preparation of this compound, I attempted to obtain it by the direct addition of pure iodine monochloride to ethene, matters being so arranged that a large excess of the hydrocarbon was present during the reaction. The result was altogether different from what I anticipated. When the two substances are brought together, nearly the whole of the iodine is set free, and Dutch liquid is formed, only a very small quantity of the chloriodide being produced: I varied the conditions of the experiment in several ways, but with invariably the same result. I have since found that Geuther has made the same observation [*]. It is remarkable that the presence of water should so completely modify the reaction. It must be remembered, however, that in an aqueous solution of iodine chloride there is always more or less free hydrochloric acid and iodic acid, a portion of the iodine chloride being decomposed in accordance with the equation

---

* *Loc. cit.*

† Proc. Roy. Soc. xi. p. 590, xii. p. 278.

$$5ICl + 3H_2O = 5HCl + HIO_3 + 2I_2,$$

the extent of the decomposition being probably dependent on the ratio of the products of decomposition to the compound still undecomposed. This supposition is rendered probable by the observations of Hannay, that, on filtering the solution from the iodine, a further precipitation gradually occurs; and that on mixing an aqueous solution of iodine chloride with carbon bisulphide, which dissolves the iodine as it separates out, the whole of the compound is gradually decomposed, nothing but iodic and hydrochloric acids being left in the water.

Dr. Maxwell Simpson kindly sent me a sample of ethene chloriodide prepared by the process above described, with the direction that in order to render it quite pure it was merely necessary to wash it with dilute potash and dry it. After being dried over phosphorus pentoxide it boiled almost completely between 139°·1 and 140°·1. Barometer 759·3 millims.; $n = 50°$, $t' = 110°$; corrected and reduced boiling-point 140°·1.

Two observations of specific gravity gave, (1) 2·13363 at 15°·28 and (2) 2·13329 at 15°·43, compared with water at 4°. Reduced to 0°, the specific gravity becomes (1) 2·16440 and (2) 2·16437. Mean 2·16439, compared with water at 4°.

Ethene chloriodide solidifies to a white crystalline mass in a mixture of snow and hydrochloric acid.

Other observers have found:—

	Boiling-point. ° °	Barometer. millims.	Specific gravity.	°
Simpson......	140–143	..	2·151	at 0
Maumené	146	753	2·39	„ 20

Observations with the dilatometer have led to the formula

$$V = 1 + 0{\cdot}000\,936\,917\,6\,t + 0{\cdot}000\,000\,415\,129\,t^2 + 0{\cdot}000\,000\,004\,501\,4\,t^3,$$

which represents with sufficient accuracy the expansion of ethene chloriodide between 0° and its boiling-point. The following Table gives the true volume of this liquid for every 5° between these intervals:—

---

[*] Jahresbericht &c. vol. xv. p. 491.

° C.	Volume.	Diff.	° C.	Volume.	Diff.
0	100000		85	108541	549
5	100470	470	90	109097	556
10	100942	472	95	109661	564
15	101416	474	100	110234	573
20	101894	478	105	110816	582
25	102375	481	110	111408	592
30	102860	485	115	112009	601
35	103349	489	120	112619	610
40	103843	494	125	113239	620
45	104341	498	130	113871	632
50	104845	504	135	114513	642
55	105354	509	140	115166	653
60	105868	514	145	115830	664
65	106389	521			
70	106916	527	140·1	1·15179	
75	107450	534			
80	107992	542			

The specific gravity of ethene chloriodide at its boiling-point is 1·87915; and its specific volume $= \frac{190 \cdot 31}{1 \cdot 87915} = 101 \cdot 27$.

It is evident from these observations that the specific volumes of bromine and iodine chloride are not equal, neither are the specific volumes of ethene bromide and ethene chloriodide; the bodies with the greater molecular weights have the greater specific volumes.

	Molecular weight.	Specific volume.
Bromine	159·90	53·62
Iodine chloride	162·31	56·32
Ethene bromide	187·90	97·30
Ethene chloriodide	190·31	101·27

The number obtained for iodine monochloride differs considerably from the volume calculated by means of Kopp's values (Cl = 22·8, I = 37·5), viz. 60·3. The specific volume of bromine (Br_2) is also less than Kopp's number, 55·6. The value assigned to chlorine is unquestionably far more accurate than that given to iodine, since the value of the latter element was calculated from only two or three compounds, whereas the former value was deduced from a comparatively large number of chlorinated products. That the value for iodine needs revision seems to be confirmed by Billet's observations of the specific gravities of liquid iodine at various temperatures. His results are*:—

Temperature ..	107°·0	111°·7	124°·3	133°·5	151°·0	170°·0
Specific gravity	4·004	3·988	3·944	3·918	3·866	3·796

If these numbers be plotted down and the curve prolonged to the boiling-point of iodine, we find that the specific gravity of iodine at this temperature is 3·780; hence the specific volume of iodine (I)

$$= \frac{126{\cdot}85}{3{\cdot}780} = 33{\cdot}5.$$

If now this value be added to that of chlorine, as given by Kopp, we get a result identical with the observed volume of iodine monochloride—

$$33{\cdot}5 + 22{\cdot}8 = 56{\cdot}3.$$

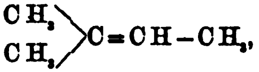
If we subtract the specific volumes of C_2H_4, as calculated by the aid of Kopp's values ($C=11$, $H=5{\cdot}5$, $C_2H_4=44$), from the specific volumes of ethene bromide and ethene chloriodide, we obtain numbers which are nearly equal to the specific volumes of bromine and iodine chloride respectively:—

$$97{\cdot}30 - 44 = 53{\cdot}30.$$
$$101{\cdot}27 - 44 = 57{\cdot}27.$$

This correspondence between the two sets of values seems to warrant the conclusion that bromine and iodine chloride possess the same volume in a compound which they have when in the free state.

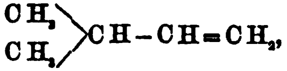
In order to ascertain how far this conclusion is general, I purpose to determine the specific volumes of such of the C_5H_{10} hydrocarbons as I can obtain in quantity and of sufficient purity, and also of the specific volumes of their combinations with bromine. Buff has already made observations upon amylene; but a recently published investigation by Flavitzky has rendered it probable that the preparation employed by Buff was a mixture of isopropylethene and trimethylethene †.

According to Flavitzky the olefine boiling at 35° is trimethylethene,



$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>C=CH-CH_3,$$

and not isopropylethene,



$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>CH-CH=CH_2,$$

which boils at 25°: both hydrocarbons are derivable from fermentation amyl-alcohol.

---

* Jahresbericht &c. vol. viii. p. 46.

† Ann. der Chem. u. Pharm. vol. clxxix. p. 340.

Since bromine and iodine chloride appear to have the same volume in union with ethene that they have when uncombined, it is not unreasonable to suppose that the same may be true of ethene itself, viz. that at its boiling-point it would possess the same volume which it has in the bromide and chloriodide at their respective boiling-points. On this assumption the specific gravity of liquid ethene would be—

Calculated from	$C_2H_4Br_2$	0·641
„ „	C_2H_4ICl	0·624

III. "Experimental Contributions to the Theory of Electrolysis." By ALFRED TRIBE, Lecturer on Chemistry in Dulwich College. Communicated by J. H. GLADSTONE, Ph.D., Fullerian Professor of Chemistry in the Royal Institution. Received January 13, 1876.

In July 1800 Nicholson and Carlisle first effected the decomposition of water by the pile of Volta; and they were not a little surprised when the constituent gases of the water appeared separately at some considerable distance from each other*, but they offered no opinion as to the cause of so singular a phenomenon. A little later Cruickshank also decomposed water by the pile, and, for the first time, many metallic salts†. He also, like Nicholson and Carlisle, was much struck by the appearance of the compounds round poles separated some distance, and attempted to explain the phenomenon by supposing that the principle of galvanism could exist in an oxygenated and deoxygenated condition—that in entering water at the negative end, it combined with oxygen, liberating hydrogen, and that on arriving at the positive end the oxygen either escaped or combined with the wire‡.

This hypothesis, which involves the idea of an imponderable capable of combining with ponderables, underwent various modifications by Fourcroy and Vauquelin and Thenard, and by Dr. Bostock and others.

But the next step of importance to the theory of electrolysis was the idea of the passage into or through the liquid of one or both constituents of the electrolyte, which was first roughly foreshadowed by an anonymous correspondent of Nicholson's Journal (vol. iv. p. 472), and which was thus more explicitly expressed in 1807 by Sir H. Davy:—"The oxygen of a portion of water is attracted by the positive surface at the same time that the other constituent part, the hydrogen, is repelled by it, and the opposite process takes place at the negative surface; and in the middle or neutral point of the circuit, whether there be a series of decompositions and recompositions, or whether the particles from the extreme points only are active, there must be a new combination of the repelled matter." (Phil. Trans. 1807, p. 30.)

---

* Nicholson's Journal, Old Series, vol. iv. p. 183.

† *Ibid.* p. 189.

‡ *Ibid.* New Series, vol. iii. p. 9.

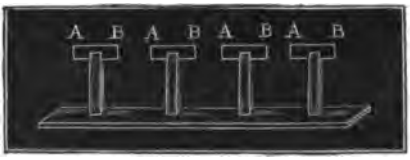
The next enrichment of the subject was by Grotthus[*], who contended that since in the elementary combinations of the pile of Volta, as in a magnet, there is polarity, it would establish a like condition in the elements of water.

Faraday, accepting the notion of polarity, added the necessary corollary, the idea of the revolution of the molecules of the electrolyte[†], which, as far as I am aware, is the last important contribution to the theory of the subject.

If the condition of an electrolyte just prior to, and in the act of, decomposition be in accordance with the views of Grotthus and Faraday, as enunciated, an electrolyte may, it appears to me, be regarded as a dielectric whose molecules are possessed of the power of mutually exchanging their constituents during discharge. This view, jointly with some supposed points of resemblance between magnetic and electrolytic substances to which it is unnecessary here to refer, led me to undertake the experiments detailed in this communication.

Experiment I.—A piece of thin copper wire about an inch long was suspended lengthwise, by a piece of cotton, between the copper electrodes (distant about 4 inches) of a Grove's battery[‡], and immersed in a 5-per-cent. solution of potassium chloride. Gas was at once given off from the end of the wire facing the positive pole, and after the lapse of a few minutes the end facing the negative battery-pole was found corroded.

Experiment II.—Four small upright wooden posts 1 inch high were fixed perpendicularly and 1 inch apart in a wooden stand 5 inches long. Slits were made in the tops of these posts, and in them were inserted strips of thin sheet silver.



The whole arrangement, as in the figure, was then placed in a glass vessel containing a 5-per cent. solution of copper sulphate mixed with a little potassium chloride, the silver strips being arranged lengthwise in a straight line between the copper electrodes. On making contact, silver chloride (resulting from the action of the potassium chloride upon the silver sulphate produced) immediately formed upon those ends of the strips facing the negative pole, and marked B in the figure above, and descended in clouds in a beautiful manner, being apparently attracted, after the lapse of a minute or two, towards the battery-poles. In a few minutes the condition of the other ends of the strips was examined, and on each there was copper distinctly visible.

---

[*] Ann. de Chimie, vol. lviii. p. 65.

[†] Tyndall on Faraday, Proc. Roy. Inst. vol. v. p. 218.

[‡] Of ten cells both in this and all the other experiments.

The preceding experiments demonstrate that an insulated conductor may, by immersion in any part of an electrolyzing fluid, become endowed with the power of doing work exactly similar in kind to that done by the two battery-electrodes; *may*, because, as will be subsequently shown, the working power of the insulated conductor is dependent more or less upon its length, position in the fluid, and conductivity, as well as chemical activity.

It is well known that the poles or electrodes of a battery are each charged with electricity opposite in kind, but possessed of similar properties to the electricity of friction, though generally much less intense. This being so, were an insulated conductor placed lengthwise, so as to ensure the maximum effect, between the electrodes of a battery, the whole being immersed in air, it is certain that, were our instruments sufficiently delicate to detect it, the end facing the positive electrode would be found charged with negative electricity, whilst the other end, facing the negative electrode, would be found charged with positive electricity. That is, the conductor would become endowed with the power of doing work similar in kind to the two battery-electrodes, just as has been shown to obtain with an insulated conductor placed between the battery-electrodes immersed in a solution of copper sulphate and potassium chloride.

Now it appears to me that the two actions just mentioned are parallel phenomena; and if the polarization of the insulated conductor immersed in air be ascribable to induction, the polarization (for such its properties show it to be) of the conductor immersed in an electrolyzing fluid may also be attributed to the same cause.

Similar phenomena to the former receive a ready explanation by means of Faraday's theory of the polarization of contiguous particles, a similar hypothesis applied to air and other dielectrics as was thirty-two years previously applied by Grotthus to what we now term electrolytes.

The difference between the two phenomena lies in the fact that a high electric tension is necessary to effect the depolarization of the particles of air by discharge, which, of course, is unaccompanied by decomposition; whereas only a very low electric tension is required to effect the depolarization of an electrolyte, which, on the contrary, is always accompanied by decomposition.

Experiments III. to VIII.—The object of these was to obtain some quantitative measure of the relative degree of polarization of the molecules of the electrolyte in its different parts, and also to ascertain the influence of the size of the electrodes on the same. Copper sulphate and silver I found to promise greater advantages than other electrolytes and conductors for these purposes.

Experiments III. and IV.—A 5-per-cent. solution of the salt was therefore employed, and a glass trough 12 inches by 4½ and about 4 inches deep. Silver plates ½ × ¼ inch were fixed on twelve uprights 1 inch distant, as previously described. The whole was immersed in the copper solution, in the centre of and between copper electrodes 4½ inches wide, *i. e.* completely across the trough, the electrodes being ⅛ inch distant from the first and last silver strips. After being connected with the battery for two hours, metallic copper was distinctly visible on the ends of each of the strips of silver facing the positive pole. The copper on the strips in this and in another precisely similar experiment was determined by the cyanide of potassium and ammonia process, after removing it by digestion with dilute hydrochloric acid containing a little nitric. One cub. centim. of the K Cy solution was equivalent to ·00309 gram of copper.

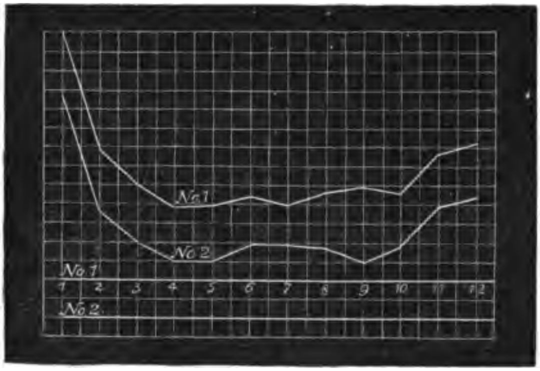
The results were as under :—

No. of Strip from + pole.	Cub. centim. of K Cy used.	
	No. 1.	No. 2.
1.	3·0	2·9
2.	2·9	3·0
3.	3·1	2·8
4.	2·9	2·9
5.	2·7	3·1
6.	3·0	2·9
7.	3·1	2·8
8.	3·2	2·9
9.	3·0	—
10.	2·7	2·6
11.	3·2	3·0
12.	2·8	3·0

Experiments V. and VI.—The 4½-inch electrodes were now replaced by others ½ inch wide, with the following result :—

No. of Strip from + pole.	Cub. centim. of K Cy used.	
	No. 1.	No. 2.
1.	6·5	5·8
2.	3·5	2·8
3.	2·6	2·0
4.	1·8	1·7
5.	2·0	1·7
6.	2·1	2·0
7.	2·0	1·9
8.	2·3	1·9
9.	2·4	1·6
10.	2·3	2·0
11.	3·3	2·8
12.	3·7	3·1

which, graphically represented, give curves as in this diagram.



These quantitative experiments also accord with the view of Grotthus. Nos. 3 and 4 would show that the whole of the molecules of the electrolyte were equipolarized, which follows from the fact that in any given section of the liquid there must have been the same number of polarized particles as in that in immediate contact with the electrodes; whereas in Experiments V. and VI. it would appear that the number of polarized particles increases as the section is removed from the electrodes, and the intensity of the action in any definite space is accordingly diminished. Grotthus's view, however, as it appears to me, does not account for the difference of polarization of the molecules in the vicinity of the two electrodes, as exhibited in Experiments V. and VI.

The principal source of error in the foregoing experiments is the difficulty of placing the strips in a straight line and perfectly parallel in direction; for if not parallel to the line joining the electrodes, the poles of each suspended conductor become closer together and less capable of doing chemical work.

This is well shown by the subjoined results of experiments made to test the influence of the position of the insulated conductors upon their activity. The same apparatus was used as for the last experiment, the positions of the strips being as represented in the Table (side by side with the results).

Direction.	K Cy used.	Direction.	K Cy used.
|	4·8 c. c.	—	2·0 c. c.
|	2·4	|	2·4
/	0·9	|	1·5
—	0·0	\	0·6
|	1·3	|	1·3
—	0·0	\	trace
\	trace	/	trace
|	1·7	|	1·3
—	0·0	—	0·0
/	0·6	|	1·3
|	2·4	|	3·2
|	3·0	/	3·3

The positive battery-electrode is supposed to be at the top and the negative at the bottom of the columns respectively.

A glance at these numbers well shows the influence of direction, and at the same time reveals the fact that a suspended rigid conductor, surrounded by an electrolyzing fluid, may transmit the electric power as though it were transparent to its influence.

The effect of varying the length of the conductor is illustrated by Experiment VII., that of conductivity by Experiment VIII., and that of chemical activity by Experiment IX.

Experiment VII.—The same arrangement was employed as in Experiment III., the silver strips ¼ inch in diameter being placed in a post midway between the electrodes, and each allowed to remain in the electrolyzing fluid for thirty minutes. The deposited copper was determined as before.

Length of Silver Strip.	Expt. I. K Cy used.	Expt. II. K Cy used.
2 inches	7·6 c. c.	8·4 c. c.
3 „	18·2	17·4

Experiment VIII.—On three posts ½ inch distant were placed:—1st, glass; 2nd, charcoal; 3rd, platinum. These were then placed between copper electrodes 3½ inches apart, the whole being immersed in solution of copper sulphate. On connexion being made with the battery, gas at once escaped from the positive ends of the metallic strip, while none was visible on either the glass or the charcoal. Upon removing the strips, after the lapse of thirty minutes, not a trace of copper could be seen on the glass, a little on the negative end of the charcoal (facing the positive electrode), and more on the platinum.

Experiment IX.—In the centre of a glass trough, containing a 5-per-cent. solution of potassium chloride, was fixed a post midway between platinum electrodes 5 inches apart. Pieces of different metals 1½ inch long and ½ inch wide were successively inserted in a slit in the upper part of the post, lengthwise in a line with the poles, and the amount of gas given off from the negative extremity during five minutes was determined.

Zinc gave	19·5 measures.
Aluminium	15·2 „
Copper	1·7 „
Lead	1·6 „
Silver..............	1·3 „
Platinum	1·0 „

In the language of Grotthus's hypothesis, the foregoing experiments may be explained thus:—The greater amount of copper found on the longer silver strip in Experiment VII. may be accounted for (1) by its being subjected to the influence of a greater number of polarized molecules, (2) by its tendency to electric equilibration being less, and (3) by the smaller number of molecules between its ends and the battery-electrodes inducing a more rapid discharge.

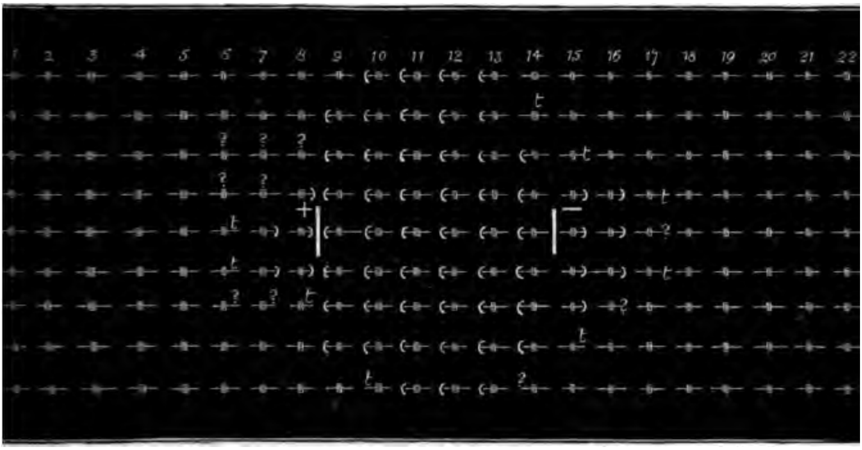
The absence of copper on the glass, the presence of a little on the carbon, and more on the platinum in Experiment VIII. is explained by the difference in the capability of these bodies to be polarized *en masse.*

The results of Experiment IX. are due in great part to the specific affinities of the metals for the chlorine of the potassium chloride; in great part, because the different metals are polarized *en masse* with more or less facility, and the result is affected accordingly; but were the conductivity of the metals equal, we might expect the rapidity of the discharge to be proportional to the specific affinities.

It now appeared desirable to obtain some experimental knowledge of the general direction of the lines of the discharge between electrodes of small dimensions.

For this purpose 198 silver strips were placed in as many posts fixed into a wooden stand. The arrangement of these, *as well as the position in which the electrodes were placed,* is shown in the accompanying diagram. Connexion was made with the battery for an hour, after which the copper sulphate was removed from the trough, and each strip examined. Those on which copper was visible, as well as its position on the strip, are thus marked in the figure, (—ı— ; *t* signifies the merest trace, and ? doubtful.

The position of the copper on the strips, indicative as it is of their electrical condition, illustrates in a striking manner the electrical condition of the molecules in the vicinity of the poles. It is also evident that the electric influence spreads itself out in the electrolyte, in the same way that the magnetic influence does in the magnetic field.



In an extension of these experiments, employing smaller electrodes and a trough of much greater dimensions, measures of the amount of action in different parts of a liquid undergoing electrolysis would be found, and these would doubtless be in accordance with what might be reckoned *à priori* from the known laws of electrical action, and would in another way exhibit the equipotential curves which Prof. Adams has worked out in his Bakerian Lecture. I hope to do this so soon as time and opportunity permit.

The work recorded above is in no way inconsistent with those current views which are usually expressed in the language of Ohm's laws; but while those views deal rather with results, the views propounded above refer to the physical processes involved, and appear to unite the different kinds of electricity more closely together.

I have much pleasure in expressing my indebtedness to Professor Gladstone for the use of the chemical laboratory of the Royal Institution, where the experimental work of this paper was done. My thanks are also due to Mr. E. J. Legg for his excellent assistance.

The following letter was read :—

South Kensington Museum, London, S.W.,
10th day of February, 1876.

Sir,—I am directed by the Lords of the Committee of Council on Education to transmit, for your information, the enclosed papers relating to the approaching Loan Exhibition of Scientific Apparatus at

2 A 2

South Kensington, and to request you to have the kindness to announce the holding of the Exhibition at the next meeting of the Royal Society, and to ask any Members who may be willing to contribute to furnish, at their earliest convenience, a description of the objects they propose to lend, on forms similar to the enclosed, which can be obtained on application to this Office.

I have the honour to be,
Sir,
Your obedient Servant,
P. Cunliffe Owen,
Director S. K. M.

The President
of the Royal Society,
Burlington House, W.

February 24, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following letter was read from the Chair:—

"13 Stratton Street,
31st January, 1876.

"My dear Hooker,—I wish to place at the disposal of the Royal Society (as the one body in which all branches of British Science are represented) the sum of £6000, to be applied (principal as well as interest) in any manner that they may consider, for the time being, most conducive to the encouragement, among our countrymen, of original research in the Physical Sciences—my object being not, on the one hand, to found a permanent endowment for the benefit of future generations, nor, on the other hand, to relieve the Government of any part of its obligation to the present; but to ascertain, as far as may be, by practical experiment on a limited scale, to what extent the progress of original research in the Physical Sciences is, in the actual position of those Sciences, retarded in this country by the want of public support to those engaged in it, and in what form an increased measure of such support would be most likely to promote its development.

"If you think that the Royal Society would be willing to carry out my wishes as thus indicated, you will oblige me by laying this proposal before your Council.

"I remain,
"Yours sincerely,
"T. J. Phillips Jodrell."

The following Papers were read :—

I. "On determining the Depth of the Sea without the use of the Sounding-line, and on an Attraction-meter." By C. WILLIAM SIEMENS, D.C.L., F.R.S., M.I.C.E. Received January 20, 1876.

(Abstract.)

The author starts with the proposition that the total gravitation of the earth, as measured on its normal surface, is composed of the separate attractions of all its parts, and that the attractive influence of each equal volume varies directly as its density and inversely as the square of its distance from the point of measurement.

The density of sea-water being about 1·026, and that of the solid constituents composing the crust of the earth about 2·763 (this being the mean density of mountain-limestone, granite, basalt, slate, and sandstone), it follows that an intervening depth of sea-water must exercise a sensible influence upon total gravitation if measured on the surface of the sea.

The amount of this influence is proved mathematically in considering, in the first place, the attractive value of any thin slice of substance in a plane perpendicular to the earth's radius, supposing the earth to be a perfect sphere, unaffected by centrifugal force, and of uniform density.

The attraction of each such slice is shown to be represented by the expression

$$ddA_1 = 2\pi dh \sin a da,$$

in which h represents the vertical distance to the slice from the point of attraction, and A_1 the total attraction of the slice.

In integrating this expression between the limits h and 0 and a and 0, this gives

$$A_1 = 2\pi h\left(1 - \tfrac{2}{3}\sqrt{\frac{h}{2R}}\right),$$

in which, for small values of h, the factor $\sqrt{\frac{h}{2R}}$ may be neglected, when the formula assumes the form

$$A_1 = 2\pi h,$$

in which A_1 represents the total attraction down to the depth h.

If A represents the total attraction of the earth, the following proportion obtains,

$$\frac{A_1}{A} = \frac{2\pi h}{\frac{4}{3}R\pi},$$

or

$$h = \tfrac{2}{3}R.$$

It follows that if sea-water was without weight, the total attraction of the earth, as measured upon the sea-surface, would diminish in the proportion of the depth to $\frac{2}{3}R$; but taking the weight of sea-water into account, gravity would be found to diminish upon the sea-level in the proportion of the depth to $\frac{614}{579}$R, or as R nearly.

The proportion would be strictly correct if the interior of the earth was of the same density as surface-rock; but the coefficient here arrived at has to be diminished in the proportion of the density of surface-rock to the mean density of the earth, or in the proportion of about $\frac{2 \cdot 75}{5 \cdot 4}$; the author considers it safer, however, not to rely entirely upon these mathematical deductions in constructing his working scale, which he prefers to base upon comparison with the sounding-line.

The author next describes a first attempt made by himself in 1859 to construct an instrument to indicate upon a scale such slight variations in total gravitation as would result from the ordinary variations of depth below a vessel, and the difficulties he then encountered. These difficulties he has since succeeded in overcoming in adopting an instrument of another construction, which he proceeds to describe in detail, reference being had to the accompanying drawings.

This instrument, which he proposes to call a *Bathometer*, consists essentially of a vertical column of mercury contained in a steel tube having cup-like extensions at both extremities, so as to increase the terminal area of the mercury. The lower cup is closed by means of a corrugated diaphragm of thin steel plate, and the weight of the column of mercury is balanced in the centre of the diaphragm by the elastic force derived from two carefully tempered spiral steel springs of the same length as the column of mercury.

One of the peculiarities of this mechanical arrangement is that it is *parathermal*, the diminishing elastic force of the springs with rise of temperature being compensated by a similar decrease of potential of the mercury column, which decrease depends upon the proportions given to the areas of the steel tube and its cup-like extensions.

The instrument is suspended a short distance above its centre of gravity in a universal joint, in order to cause it to retain its vertical position, notwithstanding the motion of the vessel; and vertical oscillations of the mercury are almost entirely prevented by a local contraction of the mercury column to a very small orifice. The reading of the instrument is effected by means of electrical contact, which is established between the end of a micrometer-screw and the centre of the elastic diaphragm. The pitch of the screw and the divisions upon the rim are so proportioned that each division represents the diminution of gravity due to one fathom of depth.

Variations in atmospheric pressure have no effect upon the reading of this instrument; but a correction has to be made for variations of atmospheric density as affecting the relative weight of the mercury column, which correction might be avoided, however, in excluding the atmosphere from both the upper and the lower surface of the mercury, and connecting the extremities of the column. The only necessary correction is that for latitude, which it is asserted in the paper must be less variable on the sea than on land, owing to the absence of masses elevated above the surface, and owing to the comparative greater distance of the irregular solid constituents of the earth and the very uniform density of sea-water.

The paper contains tables of the result of actual observations of the instrument in twice crossing the Atlantic on board the steamship 'Faraday,' while she was engaged upon laying submarine cables. The readings of the instrument were checked by actual soundings taken by means of Sir William Thomson's steel-wire sounding-apparatus; and the comparable results agree in all cases as closely as could have been expected, considering that the sounding-line gives the depth immediately below the vessel, whereas the bathometer gives the mean depth taken over a certain area, depending for extent upon the depth itself; it is also shown that upon an even slope the two instruments may be expected to agree in their indications.

It is thought that the bathometer may render useful service to the mariner in warning him of changes of depth long before reaching dangerous ground. An example is recorded where the position of the end of a submarine cable in deep water was found simply from a knowledge of the depth in which the end had been lost; and it is shown how the position of a vessel, when no astronomical observations can be taken, may be ascertained by the aid of a bathometer, provided the contour-lines of equal depths of oceanic basins were accurately laid down.

The instrument is applicable also for measuring elevations above sea-level; and it is shown that for height the total attraction of the earth varies in the ratio of

$$h : \tfrac{1}{2}R,$$

and that therefore approximately the fathom-readings at sea may be taken for yard-readings in measuring height; but that in this last application allowance will have to be made, in addition to corrections for latitude, for the local attraction of the elevated land itself, varying with its breadth, and rendering the indications of the instrument for height less reliable than for depth of sea.

ADDENDUM.—On an Attraction-meter. Received February 23, 1876.

At the reading of the foregoing paper, the author exhibited an instrument for measuring horizontal attractions, which, at the same time, illustrates the action of the bathometer. This instrument consists of a horizontal tube of wrought iron 400 millims. long, terminating at each end in a horizontal transverse tube of cast iron of 60 millims. diameter and 300 millims. long. The first-named horizontal tube is partially closed at its ends, and communicates with the transverse ubes below their horizontal mid section. The transverse tubes communicate also by means of a horizontal glass tube of 2 millims. diameter at a superior level to the former.

The whole apparatus being mounted upon three set screws is filled to the level of the half-diameter of the transverse tubes with mercury, which mercury fills also the whole of the longitudinal connecting-tube; the upper halves of the cast-iron transverse tubes and the glass connecting-tube are filled with alcohol tinted with cochineal, comprising, however, a small bubble of air, which can be made to occupy a central position in the glass tube by raising or lowering the set screws.

If a weighty object is approached to either extremity of the connecting-tube an attractive influence will be exercised upon the mercury, tending to a rise of level in the reservoir near at hand, at the expense of the more distant reservoir; and this disturbance of level between the two reservoirs must exercise a corresponding effect upon the index of air in the horizontal glass tube, moving it away from the source of attraction. The amount of this movement must be proportionate to the attractive force thus exercised, and is considerable, because the transverse cross section of each reservoir-tube is 60 × 300 = 18,000 square millims., whereas the section of the glass tube is only about 3 millims.; the motion produced by the effect of gravity is thus increased 3000-fold, and could easily be increased, say 30,000-fold, by simply increasing the horizontal area of the transverse or reservoir-tubes. Variations of temperature have no effect upon this instrument, because the liquids contained on either side of the index of air are precisely the same in amount; and the total expansion of the liquids is compensated for by an open stand-tube rising up from the centre of the connecting-tube, through which the apparatus can be easily filled. By means of this instrument the effect of 1 cwt. approached to one end or the other of the mercury connecting-tube causes a sensible motion of the air-index.

It is suggested that an instrument of this description may be employed usefully for measuring and recording the attractive influences of the sun and moon which give rise to the tides. The instrument, which is of simple construction and not liable to derangement from any cause, would have to be placed upon a solid foundation with its connecting-tube pointing east and west, records being taken either by noting the position of the index upon the graduated scale below, or by means of a self-recording arrangement through photography.

This mode of multiplying the effect produced by gravitation is shown as applicable also to the bathometer; and the author showed one of these instruments fitted with a spiral glass tube laid horizontally upon the upper surface of the bathometer upon a regularly divided scale, which horizontal tube is connected at one end with the uppermost chamber of the bathometer above the mercury, while the other end remains open to the atmosphere. The space above the mercury in the upper chamber is filled by preference with oil, which terminates in the horizontal spiral glass tube at a point which will vary with the total attractive influence of the earth, and thus furnish a means of reading the instrument. The electric contact arrangement described in the paper is thus rendered unnecessary, and the reading of the instrument much simplified.

II. "On Instruments for Recording the Direction and Velocity of Currents and the Temperature of the Water at different Depths in the Ocean." By J. Rymer Jones, of the Imperial Government Telegraphs, Japan. Communicated by Prof. Rymer Jones, F.R.S. Received January 1, 1876.

The object of these instruments is to register on board ship:—

1st. The direction of currents which flow at different depths in the ocean.

2ndly. The velocity of those currents.

3rdly. The temperature of the sea at all points between the surface and bottom, without requiring the instruments to be hauled up in order to register the results.

The advantages of such results, if capable of being obtained, must appear self-evident; and the following description will, I hope, prove the practicability of those methods which I propose to adopt in order to arrive at the above desiderata.

All three instruments are based on electrical principles.

Diag. 1. fig. 1 represents a full-sized section of the instrument employed for making serial observations of the direction of currents flowing at different depths in the sea; and in the lower part of the same figure is shown the method for taking the temperatures at the same points; but as the description of this instrument will form a separate paragraph, I shall dismiss it for the present with the remark that the same leading-wires are used in connexion with both instruments.

In considering the best method for registering the direction of deep-sea currents, two things seem absolutely necessary:—1st, some point capable of taking up a fixed direction and uninfluenced by the currents; and 2ndly, a movable point taking up the direction of, and regulated by, the current whose direction is required. With these data it appeared sufficiently easy to arrive at the direction of the currents, by measuring the angle between the fixed point and the movable point, which varies with the direction of the current. It is clear that the only available fixed point is that afforded by the unerring magnet, while the employment of a sufficiently large vane will cause the instrument to take up a position in the direction of the current, the rest being only matter of detail, which I now proceed to discuss.

In order to keep the magnet in a perfectly horizontal position and uninfluenced by any unsteadiness of the instrument, gimbals (diag. 1. fig. 1, and diag. 2. fig. 1), *g g*, are employed, as in the case of the mariner's compass; and underneath the card *c c* (diag. 1. fig. 1), to which the magnet is attached, is a copper wire (*w w*) permanently fixed at right angles to the magnet *m m*, along which an electric current is made to pass, and thus has no tendency to deflect the magnet from the magnetic meridian.

Attached to one end of this copper wire (*w w*) on the upperside, and passing through the card, is a fine platinum wire, *p p*, about 3 inches long, and tapering to a mere fibre at the top, and the wire is carefully counterpoised at the other end. The pivot on which the magnet is poised is of brass (*b*) and pointed with platinum (*p''*), and is in connexion with the sea through the pivots of the gimbals, *g g*. A double casing of thick sheet-copper (A B C D) is strengthened by stays (*i i i*) calculated to stand the great deep-sea pressures; and the air-chamber between the inside and outside casing renders the whole instrument buoyant, and is intended to take off all the strain from the line when being hauled up. *e e* is a section of an ebonite disk, the plan of which is shown in diag. 2. fig. 2; and fig. 1 is a section of the instrument taken through the dotted line BB DD, showing the ebonite disk, gimbals, card, and magnet (*m m*), with the copper wire (*w w*) affixed at right angles to it. Let into the periphery of the disk (*ee*) are sixteen pieces of brass, insulated from one another by the ebonite, but placed in such close proximity to each other that the fibrous end of the platinum wire (*p p*) must always be in contact with the under surface of one of them. Sixteen insulated wires enter the top of the instrument in the form of a cable, which divides into two parts (*h h*), eight wires on either side.

These are conducted through two holes (*h'*, *h'*) in the ebonite disk (*e e*) to the lower part of the instrument, where they pass through a second hole in the centre of the concave bottom of the compass-chamber *e'' e''*, which renders the compartment *e'' e e e''* watertight, and to the underside of which the thermometer to be afterwards described is attached. The ends of the wires are finally connected to the sixteen terminals on the back of the thermometer. Before, however, passing through the holes (*h'*, *h'*) short leading-wires are soldered to each and connected to the upper surfaces of the sixteen brass contacts on the ebonite disk (*e e*). These contacts pass through the disk and project a little beyond its lower surface, where they are grooved as in fig. 1, *o o*, in order to prevent the end of the platinum wire *p p*, which is so adjusted as to pass immediately under the centre of the groove, from trespassing beyond the line of contacts, through any unsteadiness of the instrument. These brass contacts are amalgamated on the under surface to render the contact more decided; and the top of the platinum wire *p p* must be so fine and flexible as to reduce the friction to a minimum, while at the same time it ensures perfect contact. A stuffing-box, *s' s'*, with hemp and wax pre-

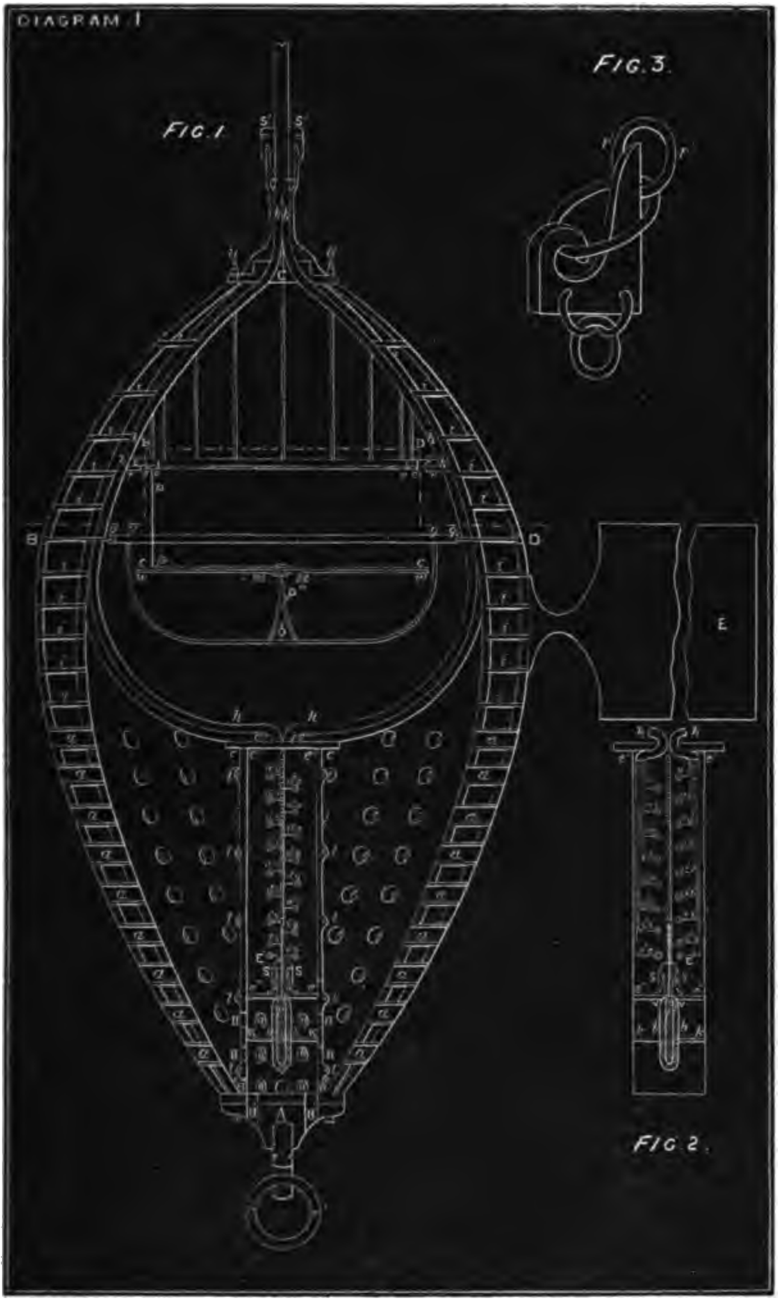
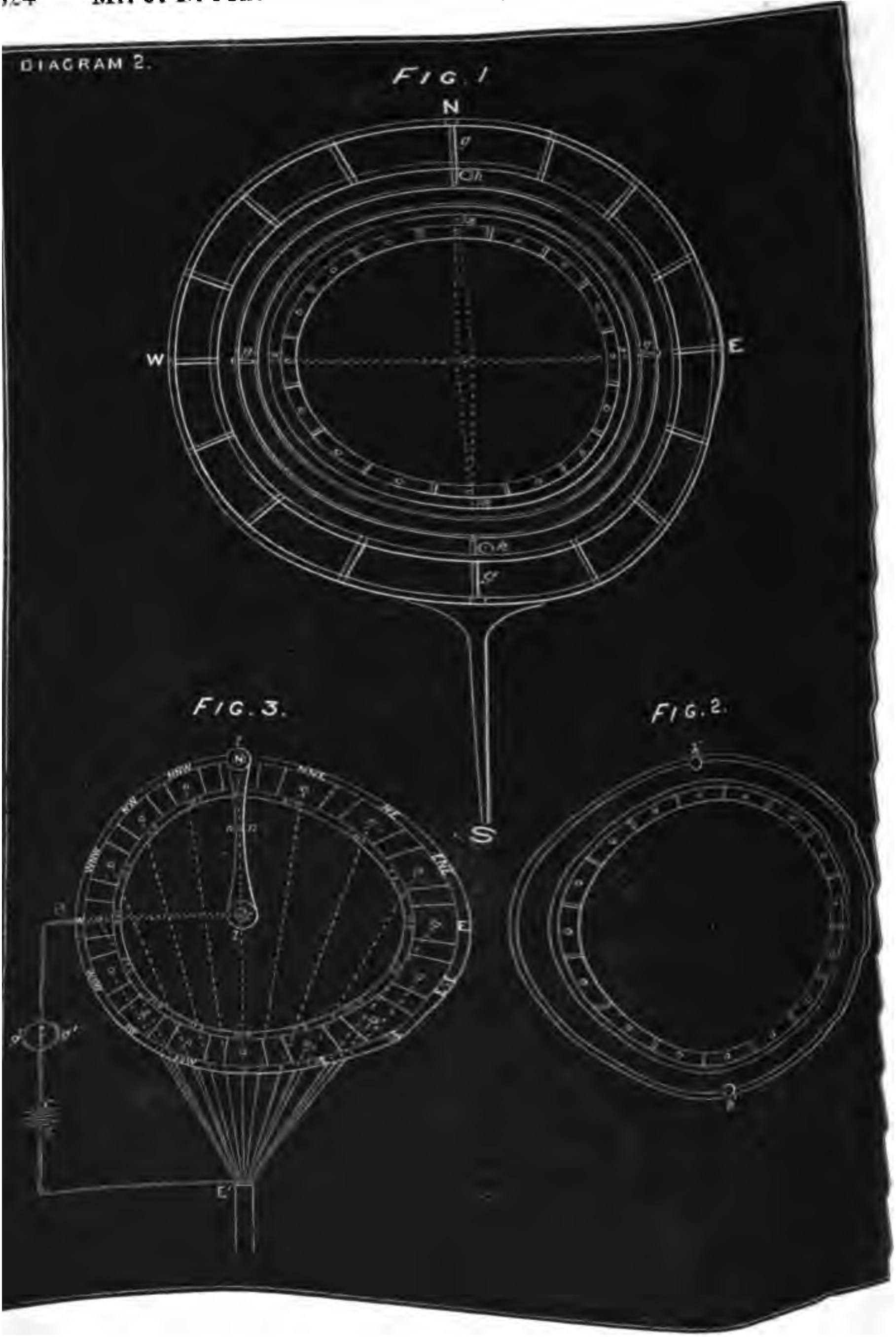


DIAGRAM I

DIAGRAM 2.



vents the leakage of sea-water through the hole by which the wires enter the top of the instrument; and the compartment *e* C *e* is filled with melted paraffin wax, which consolidates and effectually insulates the wires and contacts from one another, should any moisture find its way in.

The registering-instrument (diag. 2. fig. 3) is exceedingly simple and greatly resembles the dial-plate of Breguet's electro-magnetic dial instrument.

Around the circumference of this dial-plate are sixteen brass contacts, passing through an ebonite disk; and to the under surface of each contact is soldered one of the sixteen wires which form the core of the cable, whose other ends are soldered to the upper surfaces of the contacts on the disk (*e e*), as before mentioned.

Concentric with these metallic contacts are two circles, one on either side. In the outer circle are the rhumbs and semi-rhumbs of the wind, and in the inner circle are the degrees (Celsius) corresponding to those marked in the diagram of the thermometer, this dial-plate being capable of registering the results of both instruments.

l l is a metallic lever capable of being moved round the dial by an ebonite handle N, and the axis *x* of this lever is in connexion, through the galvanometer *g' g'*, with one pole of the battery C, the other pole Z being put to earth, E'.

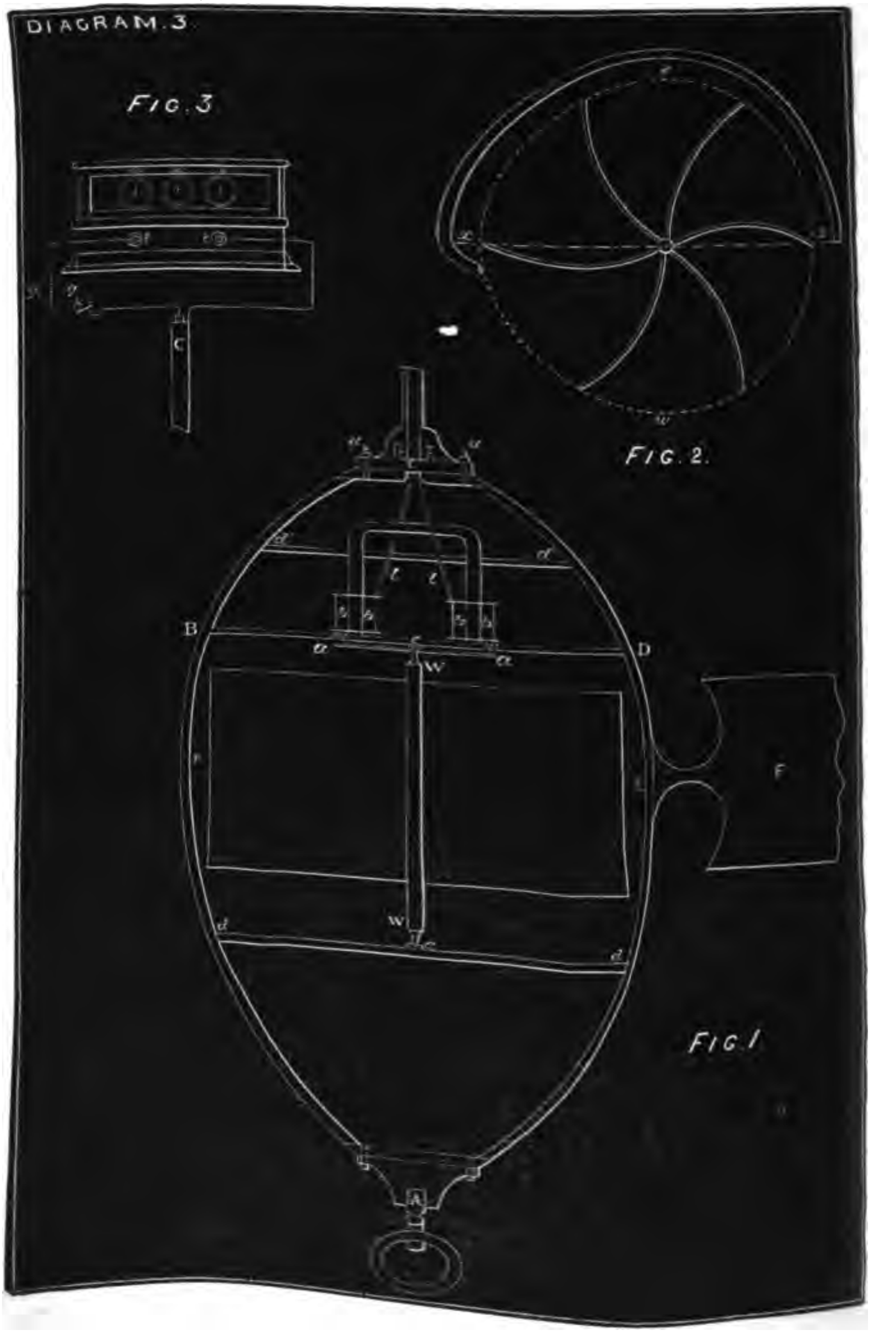
In the centre of each brass contact is an indentation for dropping the lever into; and when not in use the handle can be turned back on to itself, by means of a hinge (*n n*) in the centre, and thus break the circuit.

The different parts of the instrument having now been explained, I shall proceed to describe the manner in which it is intended to take an observation.

After attaching weights sufficiently heavy to carry the instrument steadily down in an upright position to the detaching-instrument (diag. 1. fig. 3), paying out is commenced; and under the influence of the vane E, the instrument takes up a position in the direction of the current, varying in direction as the currents vary. Whenever it is desired to take a reading, the lowering is stopped, and the instrument in mid ocean will be pointing in the direction of the current, while the magnet (*m m*) is pointing steadily to the north.

In order to understand the arrangement of the sixteen leading wires, let us suppose the instrument to be influenced by a current from the north; the direction then of the vane and magnet will coincide (diag. 2. fig. 1), and the platinum contact *p p* (diag. 1. fig. 1), attached to the copper wire *w w*, and which is always at right angles to the magnet *m m*, will be rubbing against the under surface of the contact pointing due west (W.). If, then, one of the sixteen wires in connexion with the upper surface of this contact be soldered to the under surface of the contact on the registering dial-plate marked N (diag. II. fig. 3), when lever *l l* is moved slowly over this contact, on the upper surface of the

DIAGRAM. 3



dial-plate, a current will circulate from the battery C, through galvanometer *g′ g′* (the needle of which is deflected), axis of lever *x*, lever *l l*, contact N, leading-wire to the contact against the underside of which the platinum wire is pressing, and through it and the pivots of the gimbals to earth E′, and back to the battery-pole Z, which must also be put to earth. It is clear that by calling this contact of the dial-plate north, and soldering the other fifteen wires in order to the under surfaces of the remaining contacts (as in diag. 2. fig. 3), with their other ends attached to the corresponding contacts around the periphery of the ebonite disk (*e e*) in the instrument below, in order to find the direction of any other current than a northerly one, the handle has only to be moved round the dial until the galvanometer-needle is seen to deflect; and when this is the case, the lever will be pressing against the contact whose letter represents the direction of the current which was required to be found. This reading having been duly registered, the instrument is lowered some 100 fathoms or more; and after waiting for a few minutes for the instrument to settle down in the direction of the current, the handle of the dial-plate is again turned round on board, in either direction, over the contacts until the galvanometer-needle again deflects, showing that an electric current passes; and after registering the direction of this current also, the instrument may be lowered to greater depths, and readings taken at any points between the surface and the bottom of the sea. On reaching the bottom the weights detach themselves by means of the apparatus (diag. 1. fig. 3) invented by Mr. Edward Hill, and the instrument (whose weight has been previously adjusted to enable it to float, when there is no sinker attached, and remain in an upright position) offers little weight or strain to the cable when being hauled up. The detaching-apparatus made use of is one designed by Mr. Edward Hill expressly for detaching weights; and after many trials this method has been found to be exceedingly sure and trustworthy. So long as the sinker is in mid ocean, the ring *r′ r′* remains tightly hooked on to the apparatus (fig. 3); but directly the sinker rests on the bottom and the strain is taken off, the ring *r′ r′* falls, and the form of the apparatus effectually prevents the ring *r′ r′* from rehooking the sinker when the instrument is raised; instead of which it slides up the curved surface (cf. fig.) and becomes completely detached. The detaching-apparatus is left at the bottom, after each series of observations, with the sinker; but as this can be made exceedingly cheaply, the loss is very trivial.

The cable containing the core of sixteen insulated wires must be strengthened by strands of steel wire; and it would be well to make the cable with a larger section at the top, and to taper gradually towards the end attached to the instrument below.

The strands of steel wire are intended to be finally attached to the rings in the eye-bolts *u u*, and thus take all the strain off the wires forming the core.

A part of the double casing of the instrument is also capable of being removed by means of flanges and screws, in order to afford access to the compass-box and thermometer, care being taken to readjust the portion removed so as to render it perfectly water-tight after all the internal adjustments have been looked to. The instrument must be made smaller should experience prove the present size too bulky; it will, however, be necessary to have a sufficiently long compass-needle to enable it to overcome the resistance due to the friction of the end of the platinum wire, which presses against the under surfaces of the contacts (*o o*), as above mentioned.

Instrument for measuring on board Ship the Velocities of Deep-sea Currents.

Diagram 3. fig. 1 represents a full-sized section of this instrument; and here, again, the chief characteristic is its simplicity. In outward appearance this instrument is somewhat similar to the previous one, and like it is made to place itself in the direction of the current by means of a vane F.

x z is a section of a wheel with six rays, of which fig. 2 is a full-sized plan, the section representing the part *x y z*, and being made through the centre of the wheel, as shown by the dotted line.

One half only of this wheel (*x w z*) is exposed to the free action of the water at once (cf. fig. 2). The wheel revolves on its axis (W W), which is carefully pivoted on jewels in the small brass cups, *c c*, fixed on the centres of the disks (*d d*, B D).

The upper end of this axis carries a soft armature (*a a*), which rotates with the wheel immediately under the poles of a large horseshoe magnet (*m m*). Around the poles of the magnet are two bobbins of insulated wire (*b b*), wound in opposite directions, and in connexion with them are the two leading-wires, one of which is put to earth, and the other passes up the core of the cable to the registering-instrument on board. Between the poles of the magnet and the armature (*a a*) is a disk of ebonite or boxwood or other non-conductor (B D), strengthened round the edge by a rim of brass, and sufficiently thick to prevent its warping, which is intended to render the compartment (B C D) water-tight and protect the magnet and coils.

The reason for not employing a sheet of copper or other metal is to avoid the *magnetism of rotation* discovered by Arago, or the reaction of currents induced in the copper plate by the armature revolving, as explained by Faraday; this reaction, though probably small and insignificant, is better eliminated, as the tendency is to improve the motion of the armature. The wooden disk (*d′ d′*) keeps the magnet firmly in its right place, and a stuffing-box (*s′ s′*) prevents sea-water from entering the compartment, which is also filled with paraffin wax as an additional security. The registering-instrument on board is an ordinary *double-current counter* (fig. 3), similar to those made by the British Telegraph Manufactory, Euston Road, London, and which are most suitable and trustworthy. When it is required to make an observation, a sinker is put on to the detaching-apparatus, and the instrument lowered to the required depth, where it remains steadily in a perpendicular position in the direction of the current, and the wheel commences to rotate, more quickly or slowly according to the velocity of the current influencing it, carrying round on its axis the soft iron armature (*a a*) which revolves in front of the poles of the magnet (*m m*), causing induced currents to circulate through the coils, which change in direction at every half-revolution. In order that these induced currents may circulate in the same direction through both coils of wire *b b*, the bobbins are wound, one right-handed, and the other left-handed.

These reverse currents are transmitted, on depressing the key (*k*), through the insulated wire of cable, key, galvanometer, counter, to earth E, the other leading-wire being also connected through the instrument to earth, as before mentioned. Thus a succession of reverse currents traverse the counter (fig. 3) so long as the contact-key (*k*) continues to complete the circuit, and both the counter and the wheel in mid ocean keep perfect time together. The counter may be adjusted to zero, or the position of the hands noted; and when the instrument is at the desired depth, the contact-key is held down and the counter begins to indicate the revolutions of the wheel for one minute, or for whatever period of time may be required. Thus by finding the number of revolutions produced in a given time by a current flowing with a certain known velocity, data may be obtained for finding the velocities of other streams or deep-sea currents, a constant being allowed for friction, which must be calculated. On reaching the bottom the weights are detached, and the instrument, whose weight has been previously adjusted to enable it to float and remain in a perpendicular position, offers little strain to the cable when being hauled up.

As the pressure is equally great on the inside and outside of this instrument, it is not necessary to have so strong a casing as the other instrument requires.

Instead of only two poles, as in the diagram, four poles may be used, the principle being the same as adopted by Sir Charles Wheatstone in his extremely beautiful A B C instrument, in order to get rid of the hobbling motion peculiar to other magneto-electric machines. By this arrangement the stronger current induced in the coils as the armature passes off one pole, compensates for the weaker induced current which circulates through the coils when the armature approaches the other pole, and thus makes the reverse currents much more regular. The coils must be wound so that the currents circulate in the same direction. If this method is adopted there will be four reverse currents for every revolution of the armature instead of two, as before mentioned, and the number indicated on the counter will have to be divided by two.

Presents received, February 3, 1876.

Transactions.

Bordeaux:—Société des Sciences Physiques et Naturelles. Mémoires. Tome X. pp. i–xxii, 1–42. Tables générales des 10 volumes de la 1re série. 8vo. 1875. The Society.

Dublin University Biological Association. Proceedings. Vol. I. No. 1. 8vo. 1875. The Association.

Frankfort:—Neue Zoologische Gesellschaft. Der Zoologische Garten. XV. Jahrgang. No. 7–12; XV. Jahrgang. No. 1–6. 8vo. *Frankfurt-a.-M.* 1874. The Society.

London:—Royal Agricultural Society. Journal. Second Series. Vol. XI. Part 2. 8vo. 1875. The Society.

Moscow:—Société Impériale des Naturalistes. Bulletin. Année 1874. No. 4; 1875. No. 1, 2. 8vo. *Moscou.* The Society.

Paris:—École Normale Supérieure. Annales Scientifiques. 2e Série. Tome IV. No. 6–12; Tome V. No. 1. 4to. 1875. The Institution.

Faculté des Sciences. Thèses, par R. Engel, U. Gayon, G. Lippmann, V. Neyreneuf, J. Riban. 4to. 1875. Thèses, par P. Brocchi, H. George. 8vo. 1875. The Faculty.

Rome:—R. Comitato Geologico d'Italia. Bollettino. No. 5–12. 8vo. *Roma* 1875. The Institution.

Toronto:—Canadian Institute. Canadian Journal. Vol. XIV. No. 5, 6. 8vo. 1875. The Institute.

Vienna:—Anthropologische Gesellschaft. Mittheilungen. Band V. No. 4–9. 8vo. *Wien* 1875. The Society.

K. k. Geologische Reichsanstalt. Jahrbuch. Band XXV. No. 2. Verhandlungen, 1875. No. 6–10. roy. 8vo. *Wien.* The Institution.

Österreichische Gesellschaft für Meteorologie. Zeitschrift. Band X. No. 12–24; Band XI. No. 1, 2. roy. 8vo. *Wien* 1875–76. The Society.

Clausius (R.), For. Mem. R.S. Die mechanische Wärmetheorie. Zweite Auflage. Band I. 8vo. *Braunschweig* 1876. The Author.

Hirschwald (J.) Zur Kritik des Leucitsystems. roy. 8vo. *Wien* 1875. The Author.

Hugo (le Cte L.) Une Réforme Géométrique. 8vo. *Paris* 1874. Géométrie Hugodomoidale, Anhellénique mais philosophique et architectonique. 8vo. *Paris* 1875. The Author.

Jones (Joseph) Medical and Surgical Memoirs, containing Investigations on the geographical distribution, causes, nature, relations, and treatment of various diseases. 1855–76. Vol. I. 8vo. *New Orleans* 1876. The Author.

Krafft (F.) Ueber die Entwickelung der theoretischen Chemie. 8vo. *Basel* 1875. The Author.

Mensbrugghe (G. van der) L'Électricité Statique exerce-t-elle une influence sur la tension superficielle d'un liquide? 4to. *Bruxelles* 1875. The Author.

Müller (Albert) Ein Fund vorgeschichtlicher Steingeräthe bei Basel. 4to. *Basel* 1875. The Author.

Pacini (Filippo) Dei Fenomeni e delle Funzioni di trasudamento nell' Organismo Animale. 8vo. *Firenze* 1874. The Author.

Parlatore (Filippo) Flora Italiana. Vol. V. Parte 2. 8vo. *Firenze* 1875. The Author.

Ross (Wm. A.) Pyrology or Fire Chemistry: a Science interesting to the general Philosopher, and an Art of infinite importance to the Chemist &c. roy. 8vo. *London* 1875. The Author.

Scacchi (Arcangelo) Contribuzioni Mineralogiche per servire alla storia dell' Incendio Vesuviano del mese di Aprile 1872. Parte 2. 4to. *Napoli* 1874. The Author.

Schiff (Maurizio) Sopra il Metodo seguito negli esperimenti sugli Animali viventi. 12mo. *Firenze* 1874. Sulla temperatura locale delle parti paralitiche. 8vo. 1874. Ueber die Function der mittleren und unteren Cervicalganglien des Hundes. 8vo. *Giessen.* The Author.

February 10, 1876.

Transactions.

Basel:—Naturforschende Gesellschaft. Verhandlungen. Theil VI. Heft 2. 8vo. 1875. The Society.

Leipzig:—Astronomische Gesellschaft. Vierteljahrsschrift. Jahrgang X. Heft 1, 2. 8vo. 1875. The Society.

Königsberg:—Physikalisch-ökonomische Gesellschaft. Schriften. Jahrgang XIV. Abth. 1, 2; Jahr. XV. Abth. 1, 2. 4to. 1873–74. Geological Map of the Province of Prussia. Sheets 9 & 17. The Society.

London:—Anthropological Institute. Journal. Vol. V. No. 1–3. 8vo. 1875–76. List of Members. 8vo. The Institute.

Linnean Society. Transactions. Second Series. Zoology. Vol. I. Part 2; Botany. Vol. I. Part 2. 4to. 1875. Proceedings of the Session 1874–75. 8vo. Additions to the Library, 1874–75. 8vo. List of Fellows. 8vo. The Society.

Royal Astronomical Society. Memoirs. Vol. XLII. 4to. 1875.

Transactions (*continued*).

Monthly Notices. Vol. XXXV. No. 8, 9; Vol. XXXVI. No. 1, 2. 8vo. 1875. The Society.

Royal Institution. Proceedings. Vol. VII. Part 6 (No. 63). 8vo. 1875. List of the Members. 8vo. 1875. The Institution.

Royal United-Service Institution. Journal. Vol. XIX. No. 80–83. 8vo. 1875. The Institution.

Paris:—Museum d'Histoire Naturelle. Nouvelles Archives. Tome X. fasc. 1–4. 4to. 1873–74. The Museum.

Observations, Reports, &c.

Oxford:—Radcliffe Observatory. Results of Astronomical Observations made in 1873 under the superintendence of the Rev. R. Main. Vol. XXXIII. 8vo. 1875. The Observatory.

Philadelphia:—Board of Commissioners of Public Charities of the State of Pennsylvania. Fifth Annual Report. 8vo. *Harrisburg* 1875. The Board.

Society for Alleviating the Miseries of Public Prisons. Journal of Prison Discipline. New Series. No. 14. 8vo. 1875. Outlines of Penology, by J. R. Chandler. 8vo. 1875. The Society.

Washington:—Department of Agriculture. Monthly Reports for the year 1874. 8vo. 1875. The Department.

Bertelli (Timoteo) Della Realta dei Moti microsismici ed Osservazioni sui medesimi fatte nell' anno 1873–74, nel Collegio alla querce presso Firenze. 4to. *Roma* 1875. The Author.

Clark (Latimer) Traité élémentaire de la Mesure Électrique. 8vo. *Paris* 1872. Trattato elementare delle Misurazioni elettriche, prima traduzione Italiana, per L. T. Picco. 8vo. *Genova* 1874. The Author.

Ellero (P.) I Vincolo dell' Umana Alleanza. 8vo. *Bologna* 1876. The Author.

Krueger (A.) Minnestal öfver Friedrich Wilhelm August Argelander. 4to. *Helsingfors* 1875. The Author.

Kuhn (Moriz) Ueber die Beziehung zwischen Druck, Volumen und Temperatur bei Gasen. 4to. *Wien* 1875. The Author.

Poole (S. L.) Coins of the Urtukí Turkumans (Marsden's International Numismata Orientalia. Part 2). 4to. *London* 1876. E. Thomas, F.R.S.

Wallich (Dr.) Deep-Sea Researches on the Biology of *Globigerina.* 8vo. *London* 1876. The Author.

Portrait in Oils of Richard Price, F.R.S., painted by B. West, P.R.A. Bequeathed by A. Morgan, F.R.S.

February 17, 1876.

Transactions.

Brussels:—Académie Royale de Médecine. Mémoires couronnés et autres Mémoires. Collection in 8vo. Tome III. fasc. 3. 8vo. *Bruxelles* 1875. Bulletin. Année 1875. 3^e Série. Tome IX. No. 5–11. 8vo. The Academy.

Académie Royale des Sciences. Bulletin. 44^e Année. No. 5–12. 2^e Série. Tome XXXIX., XL. 8vo. 1875. The Academy.

London:—Geological Society. Quarterly Journal. Vol. XXXI. Part 3; Vol. XXXII. Part 1. 8vo. 1875–76. List of Fellows, Nov. 1, 1875. The Society.

Quekett Microscopical Club. Journal. No. 29, 30. 8vo. 1875–76. Tenth Report, July 1875. 8vo. The Club.

Manchester:—Scientific and Mechanical Society. III. On Telegraphy by Sound; IV. Abstract of Proceedings. 8vo. 1875. The Society.

Philadelphia:—Franklin Institute. Journal. Vol. XC. No. 538, 539. 8vo. 1870; Vol. CI. No. 601. 8vo. 1876. The Institute.

Vienna:—K. k. Geologische Reichsanstalt. Abhandlungen. Band VI. Heft 2 (Das Gebirge um Hallstatt); Band VII. Heft 3 (Die Congerien- und Paludinenschichten Slavoniens und deren Fauna). 4to. *Wien* 1875. Jahrbuch. Band XXV. No. 3. 8vo. 1875. Verhandlungen. 1875. No. 11–13. 8vo. The Institution.

Ball (R. S.), F.R.S. Account of Experiments upon the retardation experienced by Vortex Rings of Air when moving through Air. 4to. *Dublin* 1872. The Author.

Dove (H. W.), For. Mem. R.S. Monatliche Mittel des Jahrganges 1874 für Druck, Temperatur, Feuchtigkeit und Niederschläge und fünftägige Wärmemittel. 4to. *Berlin* 1875. Einige Bemerkungen über die kalte Zone. 8vo. 1872. Über die Regen in Spanien. 8vo. 1873.

Über das mittlere Fortschreiten ungewöhnlicher Wärmeerscheinungen über die Erdoberfläche. 8vo. 1874. Über den allgemeinen Character milder Winter. 8vo. 1874. Kühler Mai nach mildem Januar. 8vo. 1874. Über die Übereinstimmung der Witterungserscheinungen in den ungewöhnlich trockenen Jahren 1857, 1858, 1874. 8vo. 1875. Ueber die meteorologischen Unterschiede der Nordhälfte und Südhalfte der Erde. 8vo. The Author.

Fitzgerald (R. D.) Australian Orchids. Part 1. folio. *Sydney* 1875. The Colonial Secretary of New South Wales.

Hellmann (G.) Die täglichen Veränderungen der Temperatur der Atmosphäre in Norddeutschland: Meteorologische Untersuchung. 8vo. *Berlin* 1875. The Author.

Garbich (N.) Das mechanische Dromoskop. 8vo. *Triest* 1875. The Author.

Loewenthal (Edw.) Fifty Cardinal Laws relating to the Spherical Molecular Movements as a basis for a new and remodelled system of the Sciences of Astronomy, Dynamics, Physics, and Physiology, translated by Julius Silversmith. 8vo. *Chicago* 1874. The Translator.

Monteiro (J. J.) Angola and the River Congo. 2 vols. 8vo. *London* 1875. The Author.

Parlatore (Filippo) Flora Palermitana. Tomo I. Parte 2. 8vo. *Firenze* 1847. Flora Italiana. Vol. III. Parte 1; Vol. IV. Parte 2; Vol. V. Parte 1. 8vo. *Firenze* 1858–73. The Author.

Rütimeyer (L.) Ueber Pliocen und Eisperiode auf beiden Seiten der Alpen: Ein Beitrag zu der Geschichte der Thierwelt in Italien seit der Tertiärzeit. 4to. *Basel* 1876. Weitere Beiträge zur Beurtheilung der Pferde der Quaternär-Epoche. 4to. *Zürich* 1875. Die Veränderungen der Thierwelt in der Schweiz seit Anwesenheit des Menschen. 8vo. *Basel* 1875. Spuren des Menschen aus interglaciären Ablagerungen in der Schweiz. 8vo. 1875. Ueberreste von Büffel (Bubalus) aus quaternären Ablagerungen von Europa. 8vo. 1875. The Author.

Vauthier (L. L.) The Simplon Railway Tunnel, considered in the interest of France, England, and North-west Europe. roy. 8vo. *London* 1875. The Author.

Vogel (E.) The Revelations of the Spectrum. 8vo. *San Francisco* 1875. The Author.

February 24, 1876.

Transactions.

Brussels:—Société Malacologique de Belgique. Annales. Tome IX. Année 1874. 8vo. *Bruxelles.* The Society.

Transactions (*continued*).

Harlem:—Société Hollandaise des Sciences. Archives Néerlandaises des Sciences Exactes et Naturelles. Tome X. livraison 1, 2. 8vo. *La Haye* 1875. The Society.

Nijmegen:—Nederlandsche Botanische Vereeniging. Nederlandsch Kruidkundig Archief. Verslagen en Mededeelingen. Tweede Serie. 2e Deel. 1e Stuk. 8vo. 1875. Driemaandelijksch Botanisch Literatuuroverzicht door Dr. M. Treub. No. 1, 2. 8vo. 1874. The Institution.

Pesth:—Hungarian Academy of Sciences. Evkönyvei. Kötet 14. Darab. 2–6. 4to. *Budapest* 1873–75. Archaeologiai Közlemények. Kötet IX. Füzet 2. 4to. 1874. A Magyar Nyelv Szótára. Kötet VI. roy. 8vo. 1873–74. Magyarországi Régészeti Emlékek. Kötet III. Rész 1. 4to. 1874. Icones Selectæ Hymenomycetum Hungariæ 2, 3. folio. 1874–75. Értesitöje. 7 Évfolyam, 8–14 Szám; 8 Évfolyam, 1–17 Szám; 9 Évfolyam, 1–12 Szám. 8vo. 1873–75. Név- és Tárgymutato 1–8 (1867–74). 8vo. 1875. Értekezések a Mathemat. Tudományok Köréböl. Kötet II. Szám 3–6; Kötet III. Szám 1–8; Kötet IV. Szám 1–3. 8vo. 1873–75. Értekezések a Természet Tudományok Köréböl. Kötet III. Szám 15; K. IV. S. 3–6; K. V. S. 1–11; K. VI. S. 1–6. 8vo. 1873–75. Értekezések a Nyelv- és Szeptudományok Köréböl. Kötet III. Szám 8–11; K. IV. S. 1–10. 8vo. 1873–75. Értekezések a Társadalmi Tudományok Köréböl. Kötet II. Szám 9–11; K. III. S. 1–6. 8vo. 1873–75. Értekezések a Törteneti Tudományok Köréböl. Kötet II. Szám 10; K. III. S. 1–10; K. IV. S. 1–6; K. V. S. 1. 8vo. 1873–75. Mathematikai és Természettudományi Közlemények. Kötet VII.–X. 8vo. 1869–72. Nyelvtudományi Közlemények. Kötet X. Füzet 3; K. XI.; K. XII. F. 1. 8vo. 1873–75. Magyar Történelmi Tár 19, 20, 21. 8vo. 1874–75. Török-Magyarkori Történelmi Emlékek Okmánytár. Kötet IX. 8vo. 1873. Név- es Tárgymutátó. 8vo. 1875. Monumenta Hungariæ Historica. Okmánytárak. Kötet XVIII.-XXIV. 8vo. 1873–75. Írók. Kötet XXII., XXVI., XXVII., XXXII. 8vo. 1873–75. Diplomaczia. Kötet I., II. 8vo. 1875. Nyelvemléktár. Kötet I.–III. 8vo. 1874. Monumenta Comitialia Regni Hungariæ. Kötet I., II. 8vo. 1874–75. Archivum Rákoczianum. Oszt 1. Kötet II., III., IV.; Oszt 2. Kötet II. 8vo. 1873–75. Hazai és Külföldi Folyoiratok Magyar Tudomanyos Repertorium. I. 8vo. 1874. Matlekovics, A Vasuti Különbözeti Viteldijak. 8vo. 1875. József, Magyar-Ugor Összehasonlitó Szótár. Füzet I., II. 8vo. 1872–75. Imre, Idegen es Hibás Szólások Birálata. 8vo. 1873. Almanach. 1874, 1875. 8vo. The Academy.

Transactions (*continued*).

Utrecht:—Provinciaal Utrechtsch Genootschap van Kunsten en Wetenschappen. Verslag van het Verhandelde in de Algemeene Vergadering. 8vo. 1874. Aanteekeningen van het Verhandelde in de Sectie Vergaderingen. 8vo. 1874. Peintures Murales de l'Église St. Jacques à Utrecht. folio. *Leide* 1874. The Society.

Observations &c.

Melbourne:—Observatory. Results of Observations in Meteorology, Terrestrial Magnetism, &c. Vol. III. 8vo. 1874. Monthly Record. July, August, 1875. 8vo. The Observatory.

St. Petersburg:—Observatoire Physique Central. Compte-Rendu Annuel, par A. T. Kupffer. Année 1850, 1851, 1852, 1856. 4to. Repertorium für Meteorologie. Bd. I. (Sheet 30). 4to. The Observatory.

Utrecht:—Physiologisch Laboratorium der Utrechtsche Hoogeschool. Onderzoekingen. Derde Reeks III. Afl. 2. 8vo. 1875. The Laboratory.

Antoine (Charles) De quelques propriétés mécaniques de différentes Vapeurs. 4to. *Brest* 1875. The Author.

Buchan (A.) The Diurnal Oscillations of the Barometer. Part 1. 4to. *Edinburgh* 1875. The Author.

Forrest (William) The History of Grisild the Second: a narrative in verse of the divorce of Queen Katharine of Arragon; edited by the Rev. W. D. Macray. 4to. *London* 1875 (Roxburghe Club). Baron Heath, F.R.S.

Hill (G. W.) On the Development of the Perturbative Function in Periodic Series. 8vo. The Author.

Orsoni (F.) I Microfiti ed i Microzoi della Chimica Organica ovvero alcuni studii sulle fermentazioni e sui protorganismi che le ingenerano. 4to. 1875. The Author.

Perry (Rev. S. J.), F.R.S. Notes of a Voyage to Kerguelen Island to observe the Transit of Venus, Dec. 8, 1874. 8vo. *Roehampton* 1876. The Author.

Sclater (P. L.), S.R.S., et O. Salvin, S.R.S. Nomenclator Avium Neotropicalium. folio. *Londini* 1873. The Authors.

"On the Theory of the Solution of a System of Simultaneous Non-linear Partial Differential Equations of the First Order." By E. J. NANSON. Communicated by Professor CAYLEY, F.R.S. Received June 5, read June 17, 1875[*].

Given an equation of the form

$$z=\phi(x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_r, a_{r+1}),$$

we obtain by differentiation with respect to each of the $n+r$ variables $n+r$ equations, together with the original equation $n+r+1$ equations, from which, eliminating the $r+1$ constants, we have a system of n non-linear partial differential equations.

Conversely, given a system of n non-linear partial differential equations with $n+r$ independent variables, if there exists an equation

$$z=\phi(x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_r, a_{r+1})$$

with $r+1$ constants, giving rise, as above, to the given system of n equations, then this is the "complete primitive" of the given system.

Starting with such a system of partial differential equations, it is in the present paper proposed to determine the conditions which must be satisfied in order that the system may admit of a complete primitive, and also to examine what kind of solution, if any, exists when the conditions above referred to are not satisfied.

The late Professor Boole has given an elegant method of treating a system of linear partial differential equations of the first order; but I am not aware that any one has considered the case of a non-linear system.

Let us begin with the case in which the dependent variable z is not explicitly involved in the proposed system, which can therefore be presented in the form

$$\left.\begin{aligned} &f_1(x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r})=0,\\ &f_2(x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r})=0,\\ &\vdots\\ &f_n(x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r})=0, \end{aligned}\right\} \quad \ldots\ldots\ldots \text{(i)}$$

where $p_1=\frac{dz}{dx_1}$, $p_2=\frac{dz}{dx_2}$, &c. ..., the number of equations being n, and the number of independent variables being $n+r$. It is assumed that $f_1, f_2, \ldots f_n$, considered as functions of $x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r}$, are mutually independent; if $f_1, f_2, \ldots f_n$ were not mutually independent, then, provided the given system were a consistent one, we could replace it by a new system containing a less number of equations.

Now the existence of a solution involves the supposition that values of $p_1, p_2, \ldots p_{n+r}$ can be found which will satisfy the equations (i) and at the same time render the expression

---

[*] See Proc. Roy. Soc. vol. xxiii. p. 510.

$$p_1dx_1+p_2dx_2+\ldots+p_{n+r}dx_{n+r} \quad \ldots\ldots\ldots\ldots \quad \text{(ii)}$$

a perfect differential, dz.

First suppose the functions $f_1, f_2, \ldots f_n$ are such that for every pair the condition

$$[f_i, f_j]=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}^*$$

is identically satisfied. If we determine r new functions

$$f_{n+1}, f_{n+2}, \ldots f_{n+r} \text{ of } x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r}$$

such that for every pair of the whole series $f_1, f_2, \ldots f_r$ the condition (iii) is satisfied, then the values of $p_1, p_2, \ldots p_{n+r}$ derived from the n equations (i) and the r equations

$$\left.\begin{array}{l} f_{n+1}(x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r})=a_1, \\ \vdots \\ f_{n+r}(x_1, x_2, \ldots x_{n+r}, p_1, p_2, \ldots p_{n+r})=a_r, \end{array}\right\} \quad \ldots\ldots \quad \text{(iv)}$$

where $a_1, a_2, \ldots a_r$ are any r arbitrary constants, will render the expression (ii) a perfect differential, and the value of z found by integration, viz.

$$z=\phi(x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_r)+b, \quad \ldots\ldots\ldots \quad \text{(v)}$$

b being a new arbitrary constant, will satisfy the given system (i), and will be a complete primitive in the sense above defined.

Now the determination of $f_{n+1}, f_{n+2}, \ldots f_{n+r}$ under the above conditions is a part of the problem considered in Boole's 'Differential Equations,' Supplementary volume, p. 115: the determination is there shown to be possible, and a method is given for effecting it. Hence we see that when the $\frac{1}{2}n(n-1)$ conditions $[f_i, f_j]=0$ are satisfied, the proposed system has a complete primitive.

When the given system is a linear one, these conditions are identical with those used by Boole, p. 81.

Next suppose that the condition $[f_i, f_j]=0$ is not satisfied for every pair of the functions $f_1, f_2, \ldots f_n$. Let the expressions of the form $[f_i, f_j]$ which are not zero be denoted by $\phi_1, \phi_2, \phi_3, \ldots$; then it is plain that no relation can be found which will satisfy the proposed system (i) without at the same satisfying the system of equations

$$\phi_1=0, \quad \phi_2=0, \quad \phi_3=0, \ldots;$$

hence the required solution must be sought for as the most general solution of the system

$$f_1=0, f_2=0, \ldots f_n=0, \phi_1=0, \phi_2=0, \phi_3=0, \ldots;$$

---

* Adopting the notation of Boole, Donkin, and others, the symbol $[f_i, f_j]$ is used as an abbreviation for the expression

$$\Sigma_k\left(\frac{df_i}{dx_k}\frac{df_j}{dp_k}-\frac{df_i}{dp_k}\frac{df_j}{dx_k}\right),$$

the summation extending from $k=1$ to $k=n+r$ inclusive.

if this system is inconsistent no solution exists; if it be consistent, and the functions

$$f_1, f_2, \dots f_n, \quad \phi_1, \phi_2, \phi_3, \dots$$

are not mutually independent, let it be replaced by the equivalent system

$$f_1=0, f_2=0, \dots f_n=0, f_{n+1}=0, \dots f_{n+s}=0,$$

where $f_1, f_2, \dots f_{n+s}$ are mutually independent. There are now three cases to be considered.

I. If s be greater than r, then no solution exists.

II. If $s=r$, we have $n+r$ equations to find $p_1, p_2, \dots p_{n+r}$ in terms of $x_1, x_2, \dots x_{n+r}$: if the values thus found are such as to make (ii) a perfect differential, that is if the functions $f_1, f_2, \dots f_{n+r}$ are such that for every pair the condition (iii) is satisfied, then we have an integral of the form

$$z=\phi(x_1, x_2, \dots x_{n+r})+b, \quad \dots\dots\dots\dots\dots\dots \text{(vi)}$$

containing the single arbitrary constant b. If the conditions are not satisfied then there is no solution.

III. If s be less than r, we have a system similar to the original one, only containing s more equations.

We may therefore apply the above process to this system, and so either demonstrate the non-existence of a solution, or find a complete primitive of the form

$$z=\phi(x_1, x_2, \dots x_{n+r}, a_1, a_2, \dots a_{r-s})+b,$$

that is, an integral of the form (vi), or fall upon a new system analogous to the given system (i), only containing more equations than either of the previous systems.

By continually repeating this process, it is seen that we must either arrive at a solution or prove that a solution does not exist.

We have now to consider the case in which the dependent variable z is explicity involved in the proposed system, which is therefore presentable in the form

$$\left.\begin{array}{l} f_1(z, x_1, x_2, \dots x_{n+r}, p_1, p_2, \dots p_{n+r})=0, \\ \vdots \\ f_n(z, x_1, x_2, \dots x_{n+r}, p_1, p_2, \dots p_{n+r})=0. \end{array}\right\} \quad \dots\dots\dots \text{(vii)}$$

Now let

$$\phi(z, x_1, x_2, \dots x_{n+r})=0 \quad \dots\dots\dots\dots\dots \text{(viii)}$$

be any relation between the primitive variables which satisfies the given system (vii). Differentiating (viii) with respect to each of the $n+r$ independent variables $x_1, x_2, \dots x_{n+r}$, we have

$$\frac{d\phi}{dx_1}+p_1\frac{d\phi}{dz}=0, \dots \frac{d\phi}{dx_{n+r}}+p_{n+r}\frac{d\phi}{dz}=0.$$

Hence, determining $p_1, \dots p_{n+r}$, and substituting in the proposed system (vii), we get a system of n equations of which the type is

$$f\left(z, x_1, x_2, \ldots x_{n+r}, -\frac{\frac{d\phi}{dx_1}}{\frac{d\phi}{dz}}, -\frac{\frac{d\phi}{dx_2}}{\frac{d\phi}{dz}}, \ldots -\frac{\frac{d\phi}{dx_{n+r}}}{\frac{d\phi}{dz}}\right)=0. \ldots\ldots \quad \text{(ix)}$$

Hence ϕ considered as a function of the $n+r+1$ independent variables z_1, x, x_2, $\ldots x_{n+r}$ must satisfy a system of n partial differential equations of the first order; and in this system the dependent variable does not appear explicitly. If, then, there be any value of ϕ which satisfies the system, it can be found by the method given above; and provided it involve z in its expression, the value of z found from the equation $\phi=0$ will be a solution of the original system. If z does not occur in the expression for ϕ, then the proposed system can have no solution.

Suppose the system of equations of which (ix) is the type to have a complete primitive of the form

$$\phi=\psi(z, x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_{r+1})+a_{r+2}$$

containing the $r+2$ arbitrary constants a_1, a_2, $\ldots a_{r+2}$. Then the equation $\phi=0$ gives us the value of z in the form

$$z=\theta(x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_{r+2}). \ldots\ldots\ldots\ldots \quad \text{(x)}$$

And it is to be observed that this value appears to contain one more than the number of arbitrary constants indicated by the theory of the genesis of the system (vii) as the proper number. But from the fact that (x) satisfies the system (vii) of n equations, it follows that the constants a_1, a_2, $\ldots a_{r+2}$ must be virtually equivalent to $r+1$ constants only. An instance of this occurs in the first example given below.

The results of the preceding inquiry may be collected into the following rules.

Given a system of n non-linear partial differential equations of the first order in $n+r$ independent variables, and in which the dependent variable does not explicitly appear, to find the nature of the possible solution.

Rule. Let the equations by algebraical reduction be brought to the form

$$\left.\begin{array}{l} f_1 \equiv p_1+F_1(x_1, \ldots x_{n+r}, p_{n+1}, \ldots p_{n+r})=0, \\ \vdots \\ f_n \equiv p_n+F_n(x_1, \ldots x_{n+r}, p_{n+1}, \ldots p_{n+r})=0, \end{array}\right\} \ldots\ldots\ldots \quad \text{(xi)}$$

and examine whether the condition

$$[f_i, f_j] \equiv \frac{dF_i}{dx_j}-\frac{dF_j}{dx_i}+\sum_{k=1}^{k=r}\left(\frac{dF_i}{dx_{n+k}}\cdot\frac{dF_j}{dp_{n+k}}-\frac{dF_j}{dx_{n+k}}\cdot\frac{dF_i}{dp_{n+k}}\right)=0 \,. \quad \text{(xii)}$$

is *identically* satisfied for every pair of the functions F_1, $\ldots F_n$. If it be so, then the system will have a complete primitive of the form

$$z=\phi(x_1, x_2, \ldots x_{n+r}, a_1, a_2, \ldots a_r)+b, \quad \ldots\ldots\ldots \quad \text{(xiii)}$$

which may be formed by the method of Boole referred to. But if any one of the equations of condition (xii) be not satisfied *identically*, it will constitute a new partial differential equation to be combined with the given system (xi). Let such combination be presented in the form

$$\left.\begin{aligned} f_1 &\equiv p_1 + F_1(x_1, \dots x_{n+r}, p_{n+2}, \dots p_{n+r}) = 0, \\ &\vdots \\ f_{n+1} &\equiv p_{n+1} + F_{n+1}(x_1, \dots x_{n+r}, p_{n+2}, \dots p_{n+r}) = 0. \end{aligned}\right\} \dots\dots \text{(xiv)}$$

Treating this system in the same way as we have just done (xi), we either get a solution of the form

$$z = \phi(x_1, \dots x_{n+r}, a_1, \dots a_{r-1}) + b,$$

or fall upon a system of $n+2$ equations analogous to (xi) and (xiv). Proceeding in this way we must finally arrive at a solution of the form

$$z = \phi(x_1, x_2, \dots x_{n+r}, a_1, a_2, \dots a_s) + b,$$

where n is less than r, or else we shall have the system

$$\begin{aligned} p_1 &+ F_1 \quad (x_1, x_2, \dots x_{n+r}) = 0, \\ &\vdots \\ p_{n+r} &+ F_{n+r}(x_1, x_2, \dots x_{n+r}) = 0 ; \end{aligned}$$

and if the $\frac{1}{2}(n+r)(n+r-1)$ conditions

$$\frac{dF_i}{dx_j} - \frac{dF_j}{dx_i} = 0$$

are satisfied, we have a solution

$$z = \phi(x_1, x_2, \dots x_{n+r}) + b ;$$

but if these conditions are not satisfied, then there is no solution.

Example 1. Required the integral of the simultaneous equations

$$z^2 = \left(\frac{dz}{dx_1}\right)^2 + \dots + \left(\frac{dz}{dx_n}\right)^2,$$

$$z = b_1 \frac{dz}{dx_1} + \dots b_n \frac{dz}{dx_n}.$$

Let

$$\phi(z, x_1, \dots x_n) = 0$$

be any integral, and let

$$p = \frac{d\phi}{dz}, \quad p_r = \frac{d\phi}{dx_r};$$

then

$$\begin{aligned} 2f_1 &\equiv p_1^2 + p_2^2 + \dots + p_n^2 - z^2 p^2 = 0, \\ f_2 &\equiv b_1 p_1 + b_2 p_2 + \dots + b_n p_n + zp = 0, \end{aligned}$$

and the condition $[f_1, f_2] = 0$ is satisfied. Also it is easily seen that the functions $f_3 = p_1$, $f_4 = p_2$, $\dots f_{n+1} = p_{n-1}$ satisfy the requisite conditions. Hence we take

$$p_1 = a_1, \quad p_2 = a_2, \dots p_n = a_n,$$

$$p = \frac{\sqrt{a_1^2 + a_2^2 + \dots + a_n^2}}{z},$$

$a_1, a_2, \dots a_{n-1}$ being arbitrary constants, and a_n determined by the conditions

$$a_1b_1+a_2b_2+\dots+a_nb_n+\sqrt{a_1^2+a_2^2+\dots+a_n^2}=0.$$

These values of $p_1 \dots p_n, p$ give

$$d\phi=a_1dx_1+\dots+a_ndx^2+\sqrt{\Sigma a^2}.\frac{dz}{z};$$

$$\therefore \phi=a_1x_1+\dots+a_nx_n+\sqrt{\Sigma a^2}.\log z+\mathrm{C};$$

whence the solution required is

$$a_1x_1+\dots+a_nx_n+\sqrt{\Sigma a^2}.\log z+\mathrm{C}=0,$$

which is equivalent to

$$\log z=c_1x_1+\dots+c_nx_n+\mathrm{D},$$

D being arbitrary, and $c_1 \dots c_n$ connected by the equations

$$c_1^2+\ c_2^2+\dots+\ c_n^2=1,$$
$$b_1c_1+b_2c_2+\dots+b_nc_n=1.$$

Since there are $n-1$ arbitrary constants, we have a "complete primitive" as defined above.

Example 2. Have the simultaneous equations

$$z^2=\left(\frac{dz}{dx_1}\right)^2+\dots+\left(\frac{dz^2}{dx_n}\right),$$

$$1=b_1\frac{dz}{dx_1}+\dots+b_n\frac{dz}{dx_n}$$

any solution?

Proceeding as in the last example, we find

$$2f_1\equiv p_1^2+p_2^2+\dots+p_n^2-z^2p^2=0,$$
$$f_2\equiv b_1p_1+b_2p_2+\dots+b_np_n+p=0,$$

and the condition $[f_1,f_2]=0$ is not satisfied. Accordingly we write

$$f_3\equiv[f_2,f_1]\equiv zp^2=0.$$

From these we find

$$[f_1,f_3]=z^2p^3, \quad [f_2,f_3]=p^2,$$

and are thence led to the equivalent system,

$$2f_1\equiv p_1^2+p_2^2+\dots+p_n^2=0,$$
$$f_2\equiv b_1p_1+b_2p_2+\dots+b_np_n=0,$$
$$f_3\equiv p=0.$$

Also it is easily seen that the functions

$$f_4=p_1, \quad f_5=p_2, \quad \dots f_{n+1}=p_{n-2}$$

satisfy the conditions

$$[f_i, f_j]=0.$$

Hence we take

$$p_1=a_1, \quad p_2=a_2, \ldots, p_n=a_n;$$

$a_1, a_2, \ldots a_{n-2}$ being arbitrary constants, and a_{n-1}, a_n being determined by the conditions

$$a_1^2+a_2^2+\ldots+a_n^2=0,$$

$$a_1b_1+a_2b_2+\ldots+a_nb_n=0;$$

and we find

$$d\phi=a_1dx_1+a_2dx_2+\ldots+a_ndx_n,$$

and therefore

$$\phi=a_1x_1+a_2x_2+\ldots+a_nx_n+C.$$

As this value of ϕ does not involve z, there can be no solution of the given equations. But the work has shown that the simultaneous equations

$$\left.\begin{aligned}\left(\frac{d\phi}{dx_1}\right)^2+\left(\frac{d\phi}{dx_2}\right)^2+\ldots+\left(\frac{d\phi}{dx_n}\right)^2-z^2\left(\frac{d\phi}{dz}\right)^2&=0,\\ b_1\frac{d\phi}{dx_1}+b_2\frac{d\phi}{dx_2}+\ldots+b_2\frac{d\phi}{dx_n}+\frac{d\phi}{dz}&=0\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(\alpha)$$

have an "integral"

$$\phi=a_1x_1+\ldots+a_nx_n+C$$

containing $n-1$ arbitrary constants; and that the system of simultaneous equations formed by (α) and

$$\frac{d\phi}{dz}=0$$

has the same equation for a "complete primitive."

Example 3. Find the nature of the solution of the simultaneous equations

$$x\frac{du}{dx}\left(\frac{du}{dy}+y\right)-\frac{du}{dz}-z=0,$$

$$\left(\frac{du}{dy}-z\right)^2+\left(\frac{du}{dz}-y\right)^2-2xz\frac{du}{dx}-2y=0.$$

Let

$$p=\frac{du}{dx}, \quad q=\frac{du}{dy}, \quad r=\frac{du}{dz},$$

$$\left.\begin{aligned}f_1&\equiv xp(q+y)-r-z=0,\\ \tfrac{1}{2}f_2&\equiv(q-z)^2+(r-y)^2-2xzp-2y=0.\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(\beta)$$

Then we find

$$[f_1, f_2]=(px-1)(q+r-y-z).$$

Accordingly the condition $[f_1, f_2]=0$ requires that

$$px-1=0,$$

or else that

$$q+r-y-z=0.$$

Now the first of these taken along with the equations (β) leads to the equivalent system

$$\begin{aligned} f_1 &\equiv px-1=0, \\ f_2 &\equiv q-z-r+y=0, \\ f_3 &\equiv (q-z)^2-y-z=0. \end{aligned}$$

For this system the conditions

$$[f_2,f_1]=0, \quad [f_3,f_1]=0, \quad [f_1,f_2]=0$$

are satisfied; and the values of p, q, r drawn from it being

$$p=\frac{1}{x}, \quad q=z\pm\sqrt{y+z}, \quad r=y\pm\sqrt{y+z},$$

we find an integral

$$u=\log x+yz\pm\tfrac{2}{3}(y+z)+\mathrm{C}.$$

The second equation,

$$q+r-y-z=0,$$

does not lead to any solution.

Example 4. Find the possible solution of the two simultaneous equations

$$\begin{aligned} f_1 &\equiv x^2p+y^2+zr^2-x+y=0, \\ f_2 &\equiv x^2py^2+x^2yp-xy^2-zr^2-xy=0. \end{aligned}$$

Here the condition $[f_1,f_2]=0$ is satisfied; we have then to find a function f_3 such that

$$[f_1,f_3]=0, \quad [f_2,f_3]=0,$$

and it will be easily found that

$$f_3=q^2+y$$

is a common integral. We have then

$$q^2+y=a;$$

and p, r must be found from

$$\begin{aligned} x^2p-x+zr^2 &= -a, \\ (x^2p-x)a-zr^2 &= 0; \end{aligned}$$

whence

$$\begin{aligned} p &= -\frac{a}{(1+a)x^2}+\frac{1}{x}, \\ q &= \sqrt{a-y}, \\ r &= -\sqrt{\frac{-a^2}{(1+a)z}}; \end{aligned}$$

and we get for a complete primitive

$$u=\frac{a}{(1+a)x}+\log x-\tfrac{2}{3}\,(a-y)^{\frac{3}{2}}+2\sqrt{\frac{-a^2z}{1+a}}+\mathrm{C}.$$

March 2, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

In pursuance of the Statutes, the names of the Candidates for election into the Society were read as follows:—

William de Wiveleslie Abney, Capt. R.E.
Henry Edward Armstrong, Ph.D., Sec. C.S.
John Attfield, Ph.D., F.C.S.
Charles Barry.
Robert Bentley, F.L.S.
Charles Orde Browne, Capt. R.A.
George Buchanan, M.A., M.D.
George Chesney, Lieut.-Col. R.E.
William Chimmo, Capt. R.N.
Latimer Clark, C.E., F.R.A.S.
Rev. William B. Clarke, M.A., F.G.S.
Cuthbert Collingwood, M.A., M.B., F.L.S.
James Croll (Geol. Survey, Scotl.).
Richard Daintree, F.G.S.
Herbert Davies, M.D.
Edwin Dunkin, Sec. R.A.S.
John Eric Erichsen, F.R.C.S.
Sir Thomas Fairbairn, Bart.
Sir Joseph Fayrer, M.D., K.C.S.I.
Rev. Norman Macleod Ferrers, M.A.
David Ferrier, M.A., M.D.
Augustus H. Lane Fox, Colonel.
Francis Stephen Bennet François de Chaumont, M.D.
Thomas Richard Fraser, M.D.
Alfred Henry Garrod, B.A.
Charles Alexander Gordon, M.D., C.B.
George Griffith, M.A.
Thomas Hawksley, M.I.C.E.
Robert Baldwin Hayward, M.A.
John Hughlings Jackson, M.D.
John W. Judd, F.G.S.
William Carmichael M'Intosh, M.D., F.L.S.
Robert M'Lachlan, F.L.S.
Richard Henry Major, Sec. R.G.S.
John William Mallet, Ph.D.
Charles Meldrum, M.A.
Henry Nottidge Moseley, M.A.
Richard Norris, M.D.
William Overend Priestley, M.D.
Edward James Reed, C.B.
William Roberts, B.A., M.D.
William Rutherford, M.D.
Sir Sidney Smith Saunders, C.M.G.
Michael Scott, M.Inst.C.E.
Robert Swinhoe.
George James Symons, Sec. Met. Soc.
Thomas Edward Thorpe, Ph.D., F.C.S.
Edwin T. Truman, M.R.C.S.
Henry Willett, F.G.S.
Sir Matthew Digby Wyatt.

The following Papers were read:—

I. "The Organ of Corti in Mammals." By URBAN PRITCHARD, M.D., F.R.C.S., Lecturer on Physiology (Evening Classes), King's College, London, Surgeon to the Royal Ear Dispensary. Communicated by Prof. HUXLEY, Sec.R.S., LL.D., &c. Received January 18, 1876.

(Abstract.)

I have divided my subject into three parts, namely, I. The Structure, II. The Innervation, III. The Development of the Organ of Corti, concluding with a few remarks on its function, the mode of preparation employed, and the nature of the animals examined.

Part I.—THE STRUCTURE OF THE ORGAN OF CORTI.

This apparatus, the essential portion of the cochlea, is situated partly on the lower lip of the limbus, or terminal portion of the bony lamina spiralis, and partly on the membrana basilaris; on either side it is bounded by epithelial cells, being itself developed from epithelium, as will be shown hereafter.

It consists of the following parts:—

(1) The rods or fibres of Corti.
(2) The ciliated or hair-cells.
(3) Certain nuclear cells.
(4) The supporting cells.
(5) The membrana reticularis.
(6) The membrana tectoria.

(1) *The Rods of Corti* are arranged in two rows, an inner and an outer, with their upper extremities in close contact, but separated by a considerable interval below; so that the two rows, sloping towards each other, form the roof of a triangular tunnel.

The rods stand almost in the centre of the organ, the foot of the inner rod standing on the lower lip of the limbus, and that of the outer on the membrana basilaris. On either side of the rods are situated the various cells; above and closely adherent to them is the membrana reticularis, and above this again lies the thick membrana tectoria.

The form of the rods is similar to that of a long bone, consisting of a cylindrical shaft with two enlarged extremities. The lower of these is conical in both the outer and inner rods, but their upper extremities or heads differ considerably in form. The head of the inner rod is somewhat cuboid in form, compressed laterally; and at its upper part it is prolonged into a long slender process, which overlaps and covers the head of the outer rod, this process being a direct prolongation of the upper surface. The outer surface of this rod-head presents a concavity for articulation

with the outer rod; and below the concavity is a little tubercle, from which point the head tapers off to the shaft. The inner surface is continuous with the shaft below, and forms a distinct angle with the upper surface. The sides are marked by a raised curved ridge.

The head of the outer rod is more rounded, and fits into the concavity of the inner-rod head already mentioned. From its upper part also proceeds outwards a process which is more slender than that of the inner-rod head, and passes further outwards.

The length of these rods is graduated (as I pointed out in my former paper), and ranges from $\frac{1}{150}$ inch (or ·17 millim.) at the apex of the spiral to $\frac{1}{500}$ (or ·05 millim.) at its base, where the two rods are of equal length; but proceeding upwards the outer increase in length much more rapidly than the inner, so that at the apex the former are twice the length of the latter.

The number of the rods in each row is not the same, there being three of the inner for every two of the outer. According to a careful calculation of mine, there are about 5250 inner and 3500 outer rods in each human cochlea. In substance they resemble delicate hyaline cartilage, show a tendency to split into fibres, and contain no nuclei.

(2) *The Hair-cells* are very delicate, columnar in form, with large round nuclei and nucleoli; the rest of their contents is finely granular. Their summit is flat, and from it project a row of four bristles or cilia; the rows of bristles run in the direction of the spiral.

There are four rows of these hair-cells, one situated internal to the rods, and the other three to their outer side.

The lower ends of the outer hair-cells are evenly rounded off, and both in man and in the monkey this end is enlarged, giving the cell a flask-shape; the lower end of the inner hair-cells tapers off, and the whole cell is somewhat larger than the outer ones. The summits of all these cells are attached to the membrana reticularis, and their bristles project through the circular meshes of that membrane.

(3) *The Nuclear Cells*, which include those of Claudius, Deiters, and the granular layer of Waldeyer, besides some others scattered about.

These cells have very distinct nuclei with small nucleoli, and are surrounded by some protoplasm, but have no cell-wall; they are all connected with nerve-filaments.

These are found:—1st, on the lower lip of the sulcus internal to the rods, in a mass of three irregular layers (this group has been termed the granular layer by Waldeyer). 2ndly, below the level of the outer hair-cells, and corresponding to them, are found three or four rows of these nuclear cells, which usually go by the name of the cells of Deiters. 3rdly, there is one of these cells found in each lower angle of the triangular tunnel formed by the sloping rods. Lastly, there are one or two scattered about, which will be considered with the nerves.

(4) *The Supporting Cells of Hensen* form the outer boundary of the organ;

they consist of several oval or columnar cells, which gradually merge into the epithelial cells; they form, in fact, the link between the hair-cells and the epithelium.

One or two similar cells, but with ill-defined outlines, are found forming the inner boundary of the organ; these I would term the inner supporting cells.

(5) *The Membrana Reticularis* is one of the most peculiar structures in the cochlea, and has never been satisfactorily described. It consists of a fibrous network which covers the hair-cells and rods, and is firmly attached to them. On either side it grows finer and finer, until lost among the epithelial cells. The reticulate form of this membrane is only seen when viewed from above; to the inner side of the rods there is only one row of regular circular meshes, through which the bristles of the inner hair-cells project. Over the rods and their processes the membrane passes in the form of long meshes, and in the region of the outer hair-cells it presents a very peculiar aspect. Here there are two forms of meshes—the one elongated, called a phalanx, the other circular, called an annulus, so arranged that each phalanx is surrounded by four annuli. Through the annuli project the bristles of the outer hair-cells.

Connected with this reticulate membrane, and, in my opinion, belonging to it, are found three rows of fibrous cords, situated on the outer side of each row of outer hair-cells. These cords, or trabeculæ, pass downwards to the membrana basilaris, to which they are loosely attached by an enlarged extremity. The trabeculæ have been described by other authors as belonging to the hair-cells; and Waldeyer figures them, together with the hair-cells and cells of Deiters, as forming so many twin cells. My observations totally discountenance these views, as in the upper part of the cochlea these three structures are seen to be quite separate, and again in the human fœtus the two cells are very far apart.

(6) *The Membrana Tectoria* or *Membrane of Corti.*—Great misconception existed even down to the last few years as to the form and structure of this membrane. It was regarded as an elastic membrane of equal thickness stretched straight across from the upper lip of the sulcus internus to the corresponding projection of the ligamentum spirale; nor has it yet been properly described. I quite agree with later writers in regarding it as a mucous mass secreted from the epithelial cells, and therefore soft in the fresh state; but I further regard it as only a thickened portion of a layer which lines the whole ductus cochleæ, and which I have traced right round.

The thickened portion forming the membrana tectoria commences at the attachment of the membrane of Reissner to the limbus, and passes over the teeth of the limbus as a layer of equal thickness; then passing outwards rapidly increases in thickness as it covers the organ, and gradually tapers off to the thin general layer, which, as already stated, lines the rest of the ductus cochleæ.

The bristles of the hair-cells penetrate into this membrane, which itself is analogous to the otolith mass of the vestibule.

The organ of Corti is not found at the two extremities of the lamina spiralis.

The whole organ increases regularly in breadth from base to apex of the spiral, measuring in the cat $\frac{1}{240}$ inch near the base, and $\frac{1}{120}$ inch near the apex.

The height, taken at the rod-heads, varies very little; but in the region of the outer hair-cells it again regularly increases from base to apex.

The component parts are further separated from each other on proceeding up the spiral. The rods, as already stated, increase in length, the heads widen, and the processes elongate. The hair-cells increase in height and breadth, and, lastly, the cilia or bristles themselves regularly elongate from base to apex of the cochlea.

In man and monkeys (but, curiously enough, in no other animals) a further change takes place; the number of the outer hair-cells increases from three to four, and at the apex to five rows.

These observations of mine are original, except as regards the increase in the organ as a whole.

Part II.—THE INNERVATION OF THE ORGAN OF CORTI.

The cochlear nerve in the substance of the modiolus, in passing upwards, gives off branches at right angles, which traverse a spiral ganglionic mass, the ganglion spirale, and then enter the lamina spiralis. This ganglion is situated in the lamina at the base, and gradually becoming more central in position, is found entirely in the modiolus at the apex; its cells are bipolar fusiform, averaging $\frac{1}{1000}$ of an inch in man and most mammals, but are much larger in the porpoise, averaging $\frac{1}{600}$ inch. The nerve-fibres run in bundles, which form a plexus, to the end of the lower lip of the limbus, where they perforate its upper surface, and, losing their dark borders, reach the organ of Corti. The filaments are now divided into two groups—an inner, passing to the parts internal to the rods, and an outer, passing to the opposite side of those bodies. The inner principally enter and appear to terminate in the adjacent mass of nuclear cells (the granular layer of Waldeyer); one large filament, passing through one of the nuclear cells, goes to the inner hair-cell and enters its lower extremity. The outer group may be divided into three sets, which all pass between the rods and traverse the triangular tunnel. The upper filament passes along the roof of the tunnel, and on reaching the other side of the outer rod traverses a nuclear cell, and then passes on to the first of the outer hair-cells. The middle filament traverses the centre of the tunnel and enters the same nuclear cell, besides sending a branch downwards to another of the nuclear cells. The third or lower filament runs along the floor of the tunnel, being connected with the two nuclear cells in the lower angles of it; on the outer side of the rods this filament enters the nuclear cell, which has received the descending branch from the middle filament; and this cell, again, is connected with the first cell of Deiters by another filament. Filaments in the form of festoons connect the hair-cells with each other, and analogous nervous connexions are found between the cells of Deiters. Besides these I have found numerous detached filaments, so arranged as to give the appearance of a plexus throughout the outer part of the organ.

This arrangement of the outer group of nerve-filaments has not been demonstrated before; up to the present time it is only the middle filament that has been described.

Part III.—THE DEVELOPMENT OF THE ORGAN OF CORTI.

The organ of Corti is developed from certain of the epithelial cells lining the ductus cochleæ, which at first consist of a single layer of cuboid cells; later on, those cells which line the floor and sides of the canal elongate into the columnar form, while those lining the inner part of the floor become longer still, and their nuclei multiply two, three, and fourfold. On the outer side of these are five cells, from which the chief part of the organ is developed; these I term the five primary cells.

The limbus is next developed and the sulcus formed, the latter being completely filled up by the tall columnar cells with proliferated nuclei; these, however, dwindle down again as age advances.

The contents of the first or innermost of the five primary cells are divided into two transversely, the upper division forming the inner hair-cell, the lower a nuclear cell. The same change takes place in the third, fourth, and fifth primary cells, their upper division forming the outer hair-cells, and the lower the cells of Deiters. The rods are developed from the second primary cell, which does not divide transversely, but widens at its base so as to form a triangular cell, the inner and outer sides of which thicken and form the rudimentary inner and outer rods. As this widening increases, the protoplasm disappears from the centre, forming the triangular tunnel, and the nucleus divides into two, one for each of the lower angles of the tunnel. The rods enlarge at their upper and lower extremities, but do not attain their perfect form until after birth; at this period the angle of the inner-rod head has not been developed, besides which the shafts are much thicker and more clumsy in form than in adult life.

The membrana reticularis is developed from the free border of the five primary cells and a few of the other adjacent tall ones, but the exact manner in which the reticulation is formed has not been made out.

The trabeculæ are, like the rods, developed from the side of primary cells; and although only three (on the outer side of the rods) persist in adult life, yet at birth numerous fine trabeculæ are found to the inner side of the rods.

I regard the membrana tectoria as a secretion from part of the general epithelial layer; it first appears as a thick but even layer, and as age advances that portion which covers the organ increases considerably in thickness.

From the foregoing observations it will be seen that the rods, membrana reticularis, and trabeculæ are developed from the walls of the original epithelial cells, whereas the hair- and various other cells are formed from their contents; and, lastly, that the membrana tectoria is a secretion from the same original epithelium.

The Function of the Organ of Corti.

It is generally assumed that this part of the labyrinth is concerned in appreciating the pitch and quality of sounds; and there are two prevalent theories to account for the manner in which this is accomplished. The first, Helmholtz's, assumes that each of the rods of Corti, which are not of uniform dimensions but graduated in length, as I clearly demonstrated in 1871, vibrates in unison with a certain note, when produced in the outer wall, and in vibrating affects certain nerve-filaments, which carry off the impression to the brain.

The second theory regards these rods as mere supports, and assumes the hair-cells to be the only essential structures.

The only objection of importance to Helmholtz's theory is the fact that there are no rods in the cochlea of birds.

As regards the second theory it is very incomplete, as it does not by itself explain the appreciation of the variations in pitch and quality. To make up for this deficiency, however, some further mechanical theories have been suggested.

Hensen was of opinion that the membrana basilaris, whose breadth is also graduated, acts as the mechanical appreciator, whereas Hasse believed that office to be performed by the membrana tectoria. Both of these ideas are not only very unsatisfactory but obviously fallacious, when the position and structure of these membranes are considered.

For my own part I prefer adhering to Helmholtz's view, with the modification that the rods are concerned only indirectly, and that their vibrations affect the hair-cells connected with them, so as to cause an impression to be transmitted through the nerve-filament to the brain. I consider it highly probable that the graduation in the length of the bristles alone may account for the appreciation of the variations to a considerable extent; but I cannot believe for one instant that the rods and rest of the organ are so beautifully graduated for no special purpose.

The membrana tectoria is undoubtedly analogous to the otolith mass of the vestibule; and I agree with Waldeyer in regarding it as a damper to the vibrations.

The method of preparation usually employed was as follows:—

The cochleæ were always quite fresh.

They were hardened in a $\frac{1}{4}$-per-cent. solution of chromic acid in ordinary methylated spirit; ten days required.

Decalcified in 1-per-cent. solution of nitric acid in water.

Transferred directly to gum-water, soaked a few hours, and then placed in a paper bag surrounded by spirit.

Imbedded in Stirling's machine and cut.

Gum gradually dissolved away in proof spirit.

Mounted, stained or otherwise, in glycerine or Canada balsam.

I have examined the cochleæ of the following mammals:—man, monkey, sheep, dog, cat, rat, guineapig, rabbit, porpoise, kangaroo. With the exception of the peculiarities in man and monkeys referred to, I have found a striking similarity in the organ of Corti of all these animals.

Unfortunately all my efforts to procure the cochlea of a monotreme have as yet proved unsuccessful, a circumstance much to be regretted, as I fully anticipate that it presents some appearances which link the very dissimilar cochleæ of mammals and birds.

II. "Preliminary Note on the Compound Nature of the Line-Spectra of Elementary Bodies." By J. N. Lockyer, F.R.S. Received January 20, 1876.

In a former communication to the Royal Society (Proc. vol. xxii. p. 380, 1874) I referred briefly to the possibility that the well-known line-spectra of the elementary bodies might not result from the vibration of similar molecules; and I was led to make the remark in consequence of the differences in the spectra of certain elements as observed in the spectrum of the sun and in those obtained with the ordinary instrumental appliances.

I have now clear evidence that the molecular grouping of calcium which, with a small induction-coil and small jar, gives a spectrum with its chief line in the blue, is nearly broken up in the sun, and quite broken up in the discharge from a large coil and jar, into another or others with lines in the violet.

I say "another" or "others," because I have not yet been able to determine whether the last-named lines proceed from the same or different molecules; and it is possible we may have to wait for photographs of the spectrum of the brighter stars before this point can be determined.

This result enables us to fix with very considerable accuracy the electric dissociating conditions which are equivalent to that degree of dissociation at present at work in the sun.

I beg permission to append the following Letter from Prof. Stokes and my reply:—

March 3, 1876.

My dear Lockyer,—You might perhaps like that I should put on paper the substance of the remarks I made last night as to the evidence of the dissociation of calcium.

When a solid body such as a platinum wire, traversed by a voltaic current, is heated to incandescence, we know that as the temperature increases, not only does the radiation of each particular refrangibility absolutely increase, but the proportion of the radiations of the different refrangibilities is changed, the proportion of the higher to the lower increasing with the temperature. It would be in accordance with analogy to suppose that as a rule the same would take place in an incandescent surface, though in this case the spectrum would be discontinuous instead of continuous. Thus if A, B, C, D, E denote conspicuous bright lines, of increasing refrangibility, in the spectrum of the vapour, it might very well be that at a comparatively low temperature A should be the brightest and the most persistent; at a higher temperature, while all were brighter than before, the relative brightness might be changed, and C might be the brightest and the most persistent, and at a still higher temperature E. If, now, the quantity of persistence were in each case reduced till all lines but one disappeared, the outstanding line might be A at the lowest temperature, C at the higher, E at the highest. If so, in case the vapour showed its presence by absorption but not emission, it follows, from the correspondence between absorption and emission, that at one temperature the dark line which would be the most sensitive indication of the presence of the substance would be A, at another C, at a third E. Hence, while I regard the facts you mention as evidence of the high temperature of the sun, I do not regard them as *conclusive* evidence of the dissociation of the molecule of calcium.

Yours sincerely,
G. G. Stokes.

5 Alexandra Road,
Finchley Road, N.W.,
March 5, 1876.

Dear Professor Stokes,—I was not prepared for your suggestion, as it was the abnormal and not the normal behaviour of Ca which led me to investigate it.

D is darker than any other of the Na lines, and H in the chromosphere at the Ca level is red, while in the coronal atmosphere it is green; *i. e.* the *least* refrangible line is developed by increase of temperature, and not the more refrangible one*.

I am not the less grateful to you for your suggestion; and so soon as I can obtain the use of a more powerful coil I will go over the ground as completely as I can.

---

* [The point, however, is, Which is the *most persistent* line at the respective temperatures, *i. e.* the last to disappear when the quantity of substance present is continually reduced? and Mr. Lockyer himself has shown that the line which is the most conspicuous when there is substance enough present to show several lines is by no means necessarily the most persistent.—G. G. S.]

Are you quite sure that the molecular structure of the platinum wire is constant while it behaves as you say it does?

I beg you will permit your letter and this to appear in the Proceedings. It will make my note more useful if you will.

Believe me

Very faithfully yours,

J. NORMAN LOCKYER.

III. "On the Influence of Coal-dust in Colliery Explosions." By W. GALLOWAY. Communicated by Professor FRANKLAND, F.R.S. Received February 4, 1876.

In coal-mines in which the temperature of the workings is considerably higher than the mean annual temperature at the surface, there is usually a layer of rubbish on the floor of the roadways and air-ways, which consists, in some places, almost entirely of dry coal-dust, and in others of coal-dust mixed with small pieces of coal and stone.

If it could be shown, therefore, that a mixture of air and coal-dust is inflammable at ordinary pressure and temperature, there would be no difficulty in accounting for the extent and violence of many explosions which have occurred in mines in which no large accumulations of firedamp were known to exist; for it is only necessary to suppose that a sudden gust of wind (originated, for example, by the explosion of a small accumulation of firedamp) had swept through the adjoining galleries, raising a cloud of dust into the air, and then all the other phenomena would follow in regular order. The flame of the originally inflammable mixture would pass directly into the newly formed one, expanding its volume; the disturbance would be propagated over an ever-widening area, until that area might possibly become coextensive with the workings themselves; and the consequences would be the same as if the whole space had been filled with an inflammable mixture before the disturbance began.

The accounts of colliery explosions published in this country hardly ever allude to the existence of coal-dust; and when they do so, in one or two cases, it is for the purpose of suggesting that the gases disengaged from it by the heat of the firedamp-flame would no doubt be ignited, and tend to increase the force of the explosion*. This seems all the more remarkable when it is remembered that a mixture of air with several other combustible solids in a finely divided state is explosive at ordinary pressure and temperature, and that some serious explosions have been caused by the accidental ignition of very fine dry flour suspended in the air in confined spaces.

---

* Since the above was written, my attention has been called to the following observations by Faraday and Lyell (Phil. Mag. 1845):—"In considering the extent of the fire for the moment of explosion, it is not to be supposed that firedamp is its only fuel; the coal-dust swept by the rush of wind and flame from the floor, roof, and walls of the works would instantly take fire and burn, if there were oxygen enough in the air present to support its combustion; and we found the dust adhering to the face of the pillars, props, and walls in the direction of and on the side towards the explosion,

This subject has attracted more attention in France. In the first Number of the 'Annales des Mines' for the year 1875 there are some notes referring to it, together with a paper by M. Vital, Ingénieur des Mines. M. Vital describes, in a very minute manner, all the phenomena produced by an explosion in the Campagnac colliery on the 2nd of November, 1874. A shot, which blew out the tamping, was fired in one of the working-places, in a seam of bituminous coal, and was accompanied by an explosion which burnt three men so seriously that they died within a week. No firedamp had been detected in this place at any time; but as the floor was covered with very fine, dry coal-dust, and as the shot was fired at the bottom of the face, and would consequently raise a cloud of dust, it was concluded that nothing but the instantaneous combustion of coal-dust, under the influence of the shot, could account for the accident.

The writer then describes the nature of the coal-dust, both in regard to the size of the particles and their chemical composition; and afterwards he gives an account of some experiments conducted by him in the Rodez laboratory, for the purpose of ascertaining to what extent a flame resembling that of a shot is lengthened when suddenly lanced into an atmosphere consisting of air with fine coal-dust suspended in it. In concluding, he says:—"Very fine coal-dust is a cause of danger in dry working-places in which shots are fired; in well-ventilated workings it may of itself alone give rise to disasters; in workings in which firedamp exists it increases the chances of explosion; and when an accident of this kind does occur, it aggravates the consequences."

I had carefully thought over this subject for a considerable time before I had seen M. Vital's paper, and had come to a conclusion somewhat different from his. It was this: that air mixed with certain proportions of firedamp and dry coal-dust would be explosive at ordinary pressure and temperature, although the presence of the same proportion of one of the combustible ingredients, or the other, alone, might be insufficient to confer this property on the mixture. I derived this opinion

---

increasing gradually to a certain distance as we neared the place of ignition. This deposit was, in some parts, half an inch, and in others almost an inch thick; it adhered together in a friable coked state; when examined with the glass it presented the fused round form of burnt coal-dust, and when examined chemically, and compared with the coal itself reduced to powder, was found deprived of the greater portion of the bitumen, and in some cases entirely destitute of it. There is every reason to believe that much coal-gas was made from this dust in the very air itself of the mine by the flame of the firedamp, which raised and swept it along; and much of the carbon of this dust remained unburnt only for want of air."

mmediately from the consideration that, without doubt, combustible gases can supplant each other in certain equivalent proportions in mixtures which will just ignite at given temperatures, and that finely divided combustible solids have probably the same property to some extent.

Accordingly, when an opportunity occurred on the 3rd of July last, I made experiments to test the correctness of these views. An apparatus for testing safety-lamps in an explosive current had been erected for my use at Llwynypia Colliery, in the Rhondda valley, through the kindness of Mr. A. Hood, the Managing Director, and Mr. W. G. M^cMurtrie, the Manager of the Glamorgan Coal Company's Collieries; and by having it altered slightly, I was able to employ it also in making experiments with coal-dust. This apparatus, of which fig. 1 is a vertical section, consists of a horizontal wooden box or pipe, 18 ft. 9 in. long, by 12 in. deep, by 6 in. wide inside; it was connected with the covered top of the upcast shaft by means of a vertical box of the same dimensions as itself in cross section, and 4 feet long. A and F are sliding valves for regulating or shutting off the air-current; B is a glass window, and *b* a small door on the top of the box; D a wooden pipe 4 in. square inside, by 2 ft. long; C a hopper for letting the coal-dust into the apparatus, and *c* an iron pipe 2 inches in diameter, closed at the top by a wooden plug which projected above the top of the hopper; lastly, E is a malleable iron pipe, which conducted firedamp from a closed space underground, in which there is a strong blower.

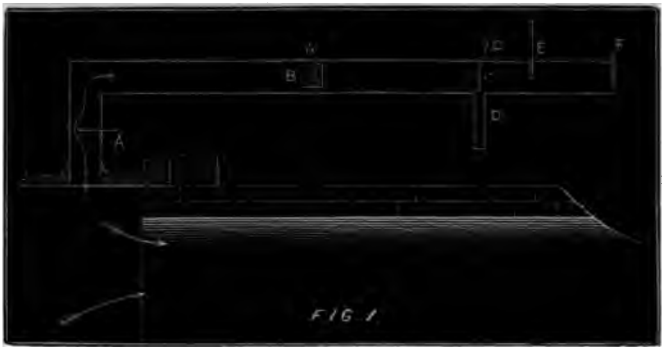


FIG. 1.

The valve at F having been closed, and that at A opened somewhat, a current of air passed up through D into the apparatus, and, flowing past B, escaped into the upcast, which is connected with an exhausting-fan. A naked light was then placed inside the apparatus at B, opposite the window; the hopper was filled with coal-dust and the plug withdrawn to a short distance above the top of *c*, and moved about gently. The coal-dust falling through *c* into the upper end of D was winnowed by the air-current; the larger particles fell down through D on to the ground below, and the fine dust, with which the whole air-current was charged, passed over the naked flame at B, and thence into the upcast. The flame of the naked light seemed to lengthen somewhat under these circumstances; but on no occasion did the mixture take fire, or show any symptoms which led me to suppose it might possibly do so. I repeated this experiment many times, both with steam-coal dust and with the finest and driest dust of the No. 3 Rhondda seam, which is an excellent coking coal, and invariably obtained the same result. The air was charged at different times with every proportion of dust, from a thin, scarcely visible cloud to one which extinguished the flame of the lamp.

The following analyses of the two kinds of coal-dust employed in these experiments have been kindly made by Dr. Frankland:—

	Steam-Coal dust.	Bituminous-Coal dust.
Carbon	85·295	82·570
Hydrogen	5·040	5·400
Oxygen (by difference)	1·261	6·030
Nitrogen	·608	1·050
Sulphur	·692	·800
Moisture	·614	·670
Ash	6·490	3·480
	100·000	100·000

In some of the experiments with coal-dust and air alone, the dust of the bituminous coal was carefully dried and sifted through muslin before being used.

The results of these experiments, and of others which I have made since, seem to indicate very conclusively that *a mixture of air and coal-dust is not inflammable at ordinary pressure and temperature.*

When, however, a small quantity of firedamp was allowed to pass into the apparatus at E, the valve F being partly opened to determine an air-current from E towards B, the mixture of air, firedamp, and coal-dust was found to be somewhat explosive.

This experiment was conducted in the following way:—A safety-lamp was placed in the apparatus at B, and the quantity of firedamp was regulated until the flame of the safety-lamp showed no indication of its presence. The safety-lamp was then removed and replaced by a naked light, and coal-dust was admitted at C. The effect was instantaneous; for, as soon as the cloud of coal-dust touched the flame, an explosion took place, and the box was filled with a red flame, which continued to burn until the supply of coal-dust was cut off or the air-valves closed. The naked light inside the apparatus was raised up to the top by means of a wire, just before the coal-dust was admitted, in order to ascertain that there was not an explosive mixture of gas and air at that point.

I have extracted the following analysis of the firedamp employed in this and all the experiments that follow from a paper by Mr. J. W. Thomas "On the Gases enclosed in Coals from the South-Wales Basin, and the Gas evolved from Blowers and by Boring into the Coal itself," printed in the Journal of the Chemical Society, September 1874.

	Composition in 100 parts.
Marsh-gas	94·78
Hydride of ethyl	0·90
Carbonic anhydride	0·72
Nitrogen	3·60
	100·00

Although I was satisfied after this with the correctness of my hypothesis in regard to mixtures of air, firedamp, and coal-dust, I could not consider this form of the experiment to be quite satisfactory; for it was always possible that the coal-dust, in falling through the branch D, might diminish the quantity of air sufficiently to enable it to form an explosive mixture with the constant quantity of gas entering the apparatus.

On the 4th of December last a serious explosion occurred in New Tredegar Colliery, and on the 6th two others followed, in Swaithe and Llan Collieries. I made an official investigation into the circumstances attending the explosion in the last-mentioned colliery, and was fortunate enough to be able to visit the workings within two and a half hours after its occurrence, when the ventilation was only partially restored. At that time the air in all the unventilated parts of the workings near the level in which the explosion had taken place (as far as they could be explored with safety) was so charged with *coal-smoke*, *soot*, and other products of the imperfect combustion of coal, that it was difficult to distinguish objects two or three feet distant.

During this and subsequent visits to these workings, I ascertained that the floor of the level already referred to was covered with a layer of dry coal-dust, mixed with small pieces of coal and stone, throughout its entire length (130 yards); that for about 50 yards next its inner end the ventilation of the level itself, and of the working-places branching from it, depended almost, if not altogether, on a convection-current and diffusion; and that firedamp was given off occasionally by the coal and strata at the face of the level, and in two other places 50 or 60 yards further out, in sufficient quantity to form small explosive accumulations. It was asserted, moreover, that no accumulation of explosive gas was known to exist anywhere in, or near, this part of the workings an hour before the accident; and as there were naked lights in each of the working-places, an explosive accumulation which might be formed in one of them could not find its way into any of the others without passing one of these lights and being ignited by it. It was impossible, therefore, that a large accumulation of gas could have been formed within the hour which preceded the explosion.

On the other hand, there were traces of coked coal-dust on the timbers, extending over a distance of 322 yards of the workings, pointing to the presence of a large body of inflammable matter; and yet the amount of damage done was insignificant. The traces on the props undoubtedly indicated the direction in which the air was travelling when the coked coal-dust was deposited; and I could not satisfactorily reconcile the various directions indicated in this way, except on the supposition that the inner end of the level (O, fig. 2) had been the origin of the explosion; that in the level itself and in the two places (O′, O″) branching from it to the dip (the only branches in which the traces were distinct), the coke was deposited during the *retrograde* movement of the air; and that in the places leading from the outer end of the level (O‴) it was deposited during its *outward* movement.

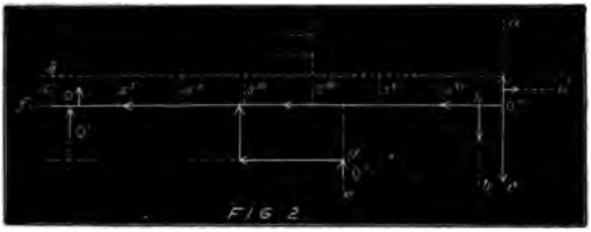


FIG 2

If we supposed, for example, that all the coke had been deposited while the air was moving *away from* the origin of explosion, it would be necessary to assume three distinct origins, one in each of the dip places at points where no gas could possibly accumulate (O′, O″), and one at the outer end of the level (O‴), where there was no cavity in the roof, and where the whole of the ventilation was passing.

Every circumstance tended to show that some explosive gas had accumulated at the inner end of the level, where there was no ventilating current; that this gas had ignited at one of the naked lights, raising a cloud of dust along the level by its explosion, and that there had been sufficient firedamp in the air occupying the level to form a weak explosive mixture when the coal-dust was added.

There could be no doubt whatever that the whole of the air in the level contained *some* firedamp, so that it became a matter of importance to ascertain the smallest quantity required to make air explosive when coal-dust is added; and with this object in view I made further experiments on the 13th of December.

The apparatus at Llwynypia Colliery was altered somewhat. Fig. 3

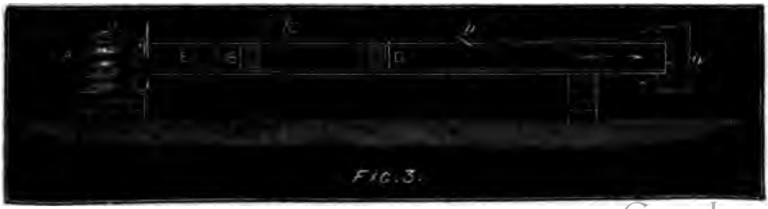


FIG. 3.

represents the new arrangement. The same wooden box was employed; but instead of connecting it to the top of the upcast, a small blowing-fan (A) driven by a steam-turbine was joined to it at one end, and the other end was left open. B and D are windows; C the hopper for coal-dust; and E one of two sluice-valves, which can be pushed into the box from each side until they meet in the middle, when they stop the air-current coming from the fan.

The fan draws the air into two chambers, one above and the other below the blades; from these chambers the air passes into the fan itself, downwards and upwards through central openings, and is expelled into the apparatus through a tangential pipe.

The firedamp-pipe passes through one of the air-holes into the lower chamber, and, being turned up at the end, terminates close to the blades.

The whole of the firedamp coming from the blower is allowed to pass into the fan; and as there is always an inward draught through the air-inlets, the whole of it passes into the apparatus thoroughly mixed with air.

The qualitative experiment with this apparatus is made in the following way:—The fan having been set in motion, a current of air and firedamp traverses the apparatus in the direction of the arrow. A safety-lamp is then placed in the box opposite the window (B), and the velocity of the current is increased by opening the valves at E until the flame of the lamp gives no indication of the presence of the firedamp. After this the safety-lamp is removed and two naked lights substituted, one opposite each window; and coal-dust is supplied through the hopper. As soon as the cloud of coal-dust reaches the flame at D, it takes fire, and either explodes backwards against the current, or fills the box with a red flame from D to the end, according to the amount of firedamp in the mixture. Meanwhile the lamp at B continues to burn exactly as before, showing no indication of the presence of the firedamp. This experiment is quite conclusive.

The quantitative experiment is slightly different. A safety-lamp is placed at B, and the valves at E are closed very gradually until the current becomes explosive; the velocity is then measured at D by means of a small anemometer, observed through the window. After this the valves are opened to any desired extent; the velocity of the current is again measured; the anemometer is removed, and a naked light substituted for it at D, and coal-dust is admitted at C.

On the 16th of December I found that the current of air and firedamp alone was just explosive when its velocity was 155 feet per minute; and two other observations, made during the intervals between the experiments with coal-dust, gave respectively 156 and 153 feet. Again, on the 5th of January it became explosive at 150 feet per minute. On the former occasion the velocity was increased to 296, 331, 337, 440, 523, and 543 feet per minute, and on the latter to 714, 808, 900, and 1060.

At the whole of these velocities the mixture became instantly inflammable when coal-dust was added to it, and filled the apparatus from B to O with a large smoky flame, which set the wood on fire when continued for more than a few seconds. At a rather higher velocity than the last, the coal-dust did not make the mixture inflammable; I did not, however, determine the exact point at which it ceased to have this effect.

By other experiments I found that a mixture consisting of 1 volume of this firedamp and 15 volumes of air is inflammable, and that with 16 volumes of air it is not inflammable at a temperature of 57° Fahr. Making use of these data, then, to calculate the composition of the mixture passing through the apparatus during the last of the second series of experiments, we find that the relative volumes of gas and air were 9·375 and 140·625 at a velocity of 150 feet per minute; whereas they were 9·375 and 1050·625 at 1060 feet per minute, or 1 firedamp to 112·06 air in the latter case.

In order to obtain reliable results from these experiments, it was necessary to have some means of ascertaining that the whole of the firedamp entered the apparatus at the low velocities, and that the fan exerted no exhausting force on the gas-pipe in the opposite cases. For this purpose the 2-in. gas-pipe was terminated at a distance of 16 inches from the fan, and the gas was conducted from this point to the centre of the fan-chamber, through a 1⅝-inch pipe fitted loosely into the former to a distance of about a foot; a very delicate means of observing the state of the pressure in the gas-pipe was also provided by having a small hole punched in it at a distance of 15 feet from the fan, and keeping a jet of gas continually burning at that point.

When the velocity of the current was low, gas escaped through the space between the two pipes, and discovered its presence when a light was applied to it. It was then necessary to close some of the air-inlets to the fan, either partially or wholly, until a flame held at the junction of the gas-pipes was drawn inwards; at the same time the flame of the jet 15 feet off had to be carefully observed, so that the closing of the inlets might not be carried too far. When the velocity was greatest, on the other hand, all the air-inlets were opened; and although air was drawn through the junction of the gas-pipes, the height of the flame of the jet already referred to did not diminish to an appreciable extent.

Having ascertained in the manner just described that when air contains only a very small quantity of firedamp (0·892 per cent. of its volume) it is capable of forming an inflammable mixture with coal-dust, we are naturally led to inquire into the means by which the presence of firedamp is usually ascertained in mines; and we find that the universal practice at the present day is to carry a safety-lamp into the atmosphere to be examined, and observe the indications of the flame. When the atmosphere is explosive, or nearly so, these indications are unmistakable; but when the proportion of firedamp is small, it is necessary to pull down the wick until the flame is only about an eighth of an inch high (that is to say, until it has little or no yellow colour remaining), and observe whether it has a "cap" above it or not. The cap is a spindle-shaped or conical blue flame, more transparent than, and appearing to rest upon, the oil-flame; it seems to be due to the combustion of that part of the mixture of firedamp and air which becomes heated to the temperature at which its active constituents can combine. It is known that when the cap is large, there is much firedamp in the air; when it is small that there is little; and when there is no cap, it is almost, if not quite universally assumed that there is no firedamp present.

There is not, however, so far as I know, any published information of a definite kind concerning the appearances presented by the cap in mixtures of firedamp and air in different proportions; I have therefore made a few experiments in order to obtain these data for the purposes of this paper. The experiments were made on the 17th of January, in the cabin near the bottom of the No. 3 Pit, Llwynypia Colliery. The firedamp employed was from the same source as that with which the coal-dust experiments were made, and was obtained from a pipe close to the door of the cabin. The apparatus consisted of a measuring-cylinder, a mixing-cylinder, a lamp, a bucket for holding water, and some india-rubber tubes. The measuring-cylinder (fig. 4) is 10 inches long by 2 inches in diameter; it has a cock (*a* and *b*) in the middle at each end, and a branch cock from each of these (*c* and *d*); it has also a water-gauge *e*, opposite which there are marks and figures on the cylinder showing the parts into which its volume can be divided. The mixing-

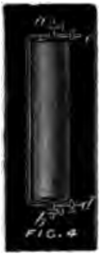


FIG. 4

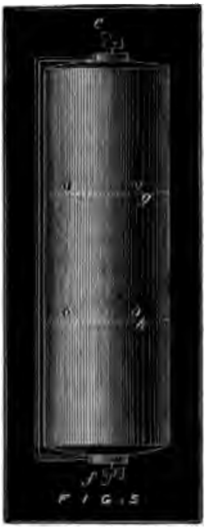


FIG. 5

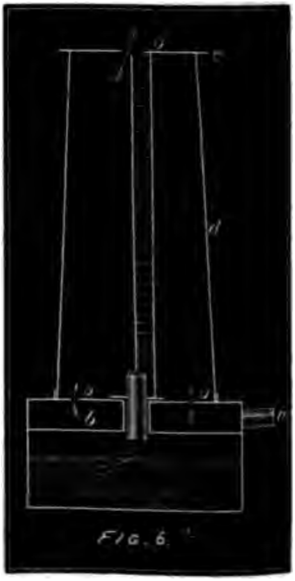
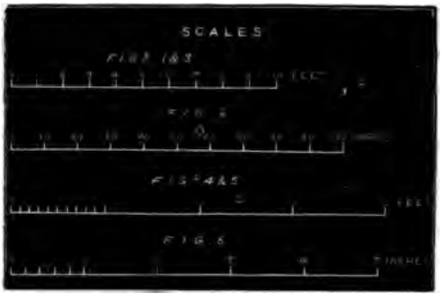


FIG. 6.

cylinder (fig. 5) is 2 feet long by 8 inches in diameter; it has a cock (*e* and *f*) at each end, a water-gauge at the side, and a scale, each division of which represents one volume of the measuring-cylinder. In the interior it is divided into three compartments by two diaphragms (*g* and *h*); these compartments communicate with each other through ten ¼-inch holes (*o o*) in each diaphragm, ranged in a circle whose centre is the axis of the cylinder. Fig. 6 represents the essential parts of the lamp apparatus in section. It consists of a wick-holder and an oil vessel, above which there is a chamber *b*, with a branch pipe (*a*) on one side and a circular opening (*o o*) on the top. This is surmounted by a glass chimney (*d*) covered on the top with a piece of tin-plate (*c*), in which there is a ⅜-inch round hole (*b*). The water-bucket is of the same capacity as the mixing-cylinder, and has a cock on one side at the bottom. The india-rubber tubes are used for the purpose of connecting the cylinders with each other, with the water-bucket, &c. Each cylinder can be filled with water or emptied, as may be required, by connecting the cock at its lower end with the one in the water-bucket, and placing it below or above the level of the water in that vessel after the cocks have been opened.



Both cylinders are filled with water in the first place: the water in the larger one is then allowed to flow out, the cock at its upper end being open to the atmosphere, until it contains any desired number of volumes of air, each volume equal to the capacity of the smaller cylinder.

The cock at the top of the smaller cylinder is connected with the gas-pipe; the branch cock *c* is opened, and firedamp allowed to pass through it so as to expel the air from the india-rubber tube; the jet of gas is ignited and kept burning, while the water is permitted to flow out at *b* until the required volume of gas is obtained: all the cocks are then closed.

The two cylinders are now connected together at both top and bottom, care being taken that the upper connecting-tube is filled with firedamp and the lower one with water when the connexion is made; the four cocks are opened, and the small cylinder is so placed that its top is just below the level of the water in the other. The gas is thus quickly transferred to the mixing-cylinder, and after this all the cocks are closed and the cylinders disconnected.

With this apparatus the volumes of gas and air can be measured with considerable accuracy and rapidity.

The quantity of water remaining in the mixing-cylinder varied in the different experiments from 60 to 300 cubic inches. Accordingly, when this cylinder was inverted, the water ran down through the holes in the diaphragms into the lowest compartment, and a corresponding volume of the gases was forced to take the opposite course; and I found that by inverting it forty times in succession and pausing each time until the sound of the running water had ceased, a comparatively perfect mixture of the gases was obtained for each experiment. The homogeneity of the different parts of these mixtures was attested by the fact that, whereas the whole of the one composed of 1 volume of firedamp and 15 volumes of air was inflammable, none of the mixture of 1 firedamp to 16 air was so.

The wick of the lamp (fig. 6) having been carefully trimmed, was drawn down until the flame presented the appearance of a small blue hemisphere, about $\frac{1}{8}$ inch high by $\frac{1}{4}$ inch diameter at the base, and having a conical speck of yellow in the middle near the top; the tube *a* was then connected with the top of the mixing-cylinder, and the mixture was forced into the chamber *b* at the rate of about $2\frac{1}{2}$ cubic inches per second. All other lights were removed from the cabin during this part of the experiment, and the various phenomena were observed in what would have been total darkness but for the feeble light of the lamp itself.

The different mixtures employed consisted of 1 volume of firedamp to 14, 15, 16, 18, 20, 25, 30, 40, 50, and 60 volumes of air. The experi-

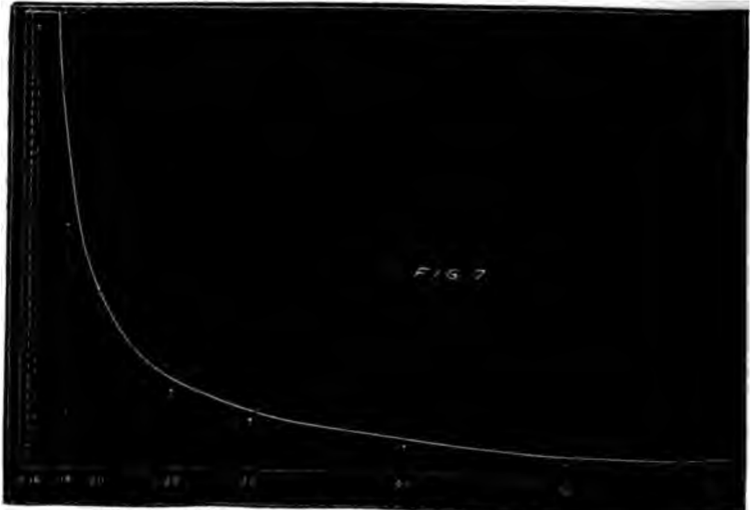


FIG. 7

The dotted line between 15 and 16 represents the asymptote.

ments were begun at 11 A.M., and concluded at 6 P.M. The meteorological observations inside the cabin at 3.15 P.M. were:—temp. 57° Fahr.; humidity 79; bar. 30·15. The same water was employed in all the experiments; and it may be safely assumed that the humidity of the mixtures of firedamp and air was 100.

The following phenomena were observed in connexion with the different mixtures:—

1 firedamp to 14 air—slightly explosive.

1 to 15—inflammable: the flame of the mixture would not pass down through the hole in the tin-plate cover of the chimney; but when the small flame, employed to ignite it, was put through the hole to a depth of ¼ inch or so below the tin-plate cover, the mixture ignited, and a horizontal, waving sheet of blue flame, occupying the whole sectional area of the chimney, passed down through it in about two or three seconds, and was extinguished on reaching the bottom.

1 to 16 gave a voluminous, waving, spindle-shaped, pale blue cap 3⅜ inches high.

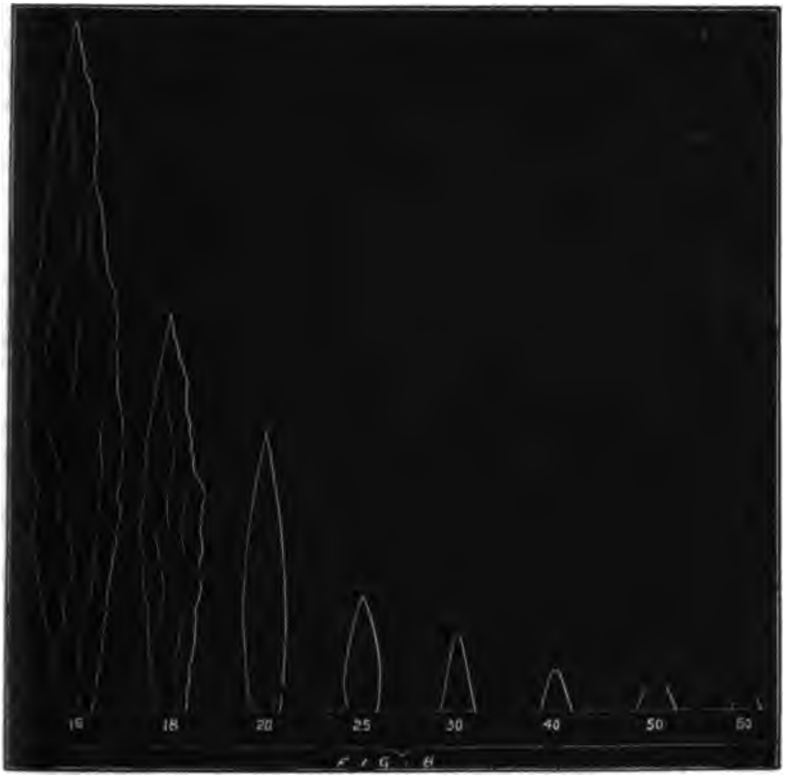


Fig. 8 represents the forms and sectional dimensions of the various "caps," from sketches and measurements taken at the time they were observed.

1 to 18—a similar cap 2 inches high, which burned rather more steadily.

1 to 20—a cap $1\frac{5}{16}$ inch high, with nearly parallel sides to about two thirds of its height, and drawn out to a point at the top. This cap was perfectly steady, and more distinct than any of the others.

1 to 25—a conical cap $\frac{1}{2}$ to $\frac{5}{8}$ inch high.

1 to 30—a conical cap $\frac{3}{8}$ inch high.

1 to 40—a conical cap $\frac{3}{16}$ to $\frac{1}{4}$ inch high.

1 to 50—an exceedingly faint cap $\frac{1}{8}$ inch high, the top having the appearance of being broken off.

1 to 60—it was hardly possible to distinguish any thing above the small oil-flame. If there was any cap (which the manager of the pit and two of the firemen who were present considered excessively doubtful), it was represented by the frustum of a cone, of which the sides only were visible, little more than $\frac{1}{16}$ inch high.

The firemen, whose principal occupation is to examine the workings daily for any symptoms of firedamp, both asserted positively that they would consider an atmosphere in which the small oil-flame burned as it did in this mixture to be *perfectly free from gas.*

When the height of the oil-flame was increased to $\frac{1}{4}$ inch it became luminous, and then the cap was invisible in all the mixtures consisting of 1 volume of gas to 25 volumes and upwards of air. Similarly, the cap is invisible in all mixtures down to the explosive one with higher oil-flames.

On comparing these results graphically (fig. 7), the divisions of the base line, measured from left to right, representing the number of volumes of air to one of firedamp, and the length of the ordinates giving the heights of the corresponding caps, measured from the top of the oil-flame, it is seen that the curve drawn through the extremities of the ordinates is roughly approximate to the form of a rectangular hyperbola. I have therefore drawn that curve for comparison through the top of the ordinate which corresponds to 20 volumes of air.

It is evident that the *heights* of these caps are in some degree proportional to the *quantity* of firedamp consumed above the oil-flame per unit of time; and, although the methods by which they were obtained are far from perfect, the results seem to point to the existence of a simple relationship between the initial temperature, the heat of combustion, and the specific heat of the various gases contained in the mixtures.

To recapitulate in a summary manner what has been already said in the preceding pages of this paper, we have now two principal facts before us, which are these :—

1. A mixture of firedamp and air, in the proportion of 1 volume of the former to 60, or more, volumes of the latter, gives no reliable indication of the presence of the inflammable gas, when tested in the manner usually, if not always, adopted in mines.

2. A mixture of firedamp and air, in the proportion of 1 volume of the former to 112 of the latter, becomes inflammable at ordinary pressure

and temperature, when charged with fine dry coal-dust, such as that which is to be found on the roadways in dry coal-mines.

It seems, therefore, only reasonable to conclude that an explosion, *originated in any way whatever*, in a mine of this class, may extend itself to remote parts of the workings *where the presence of firedamp was quite unsuspected.*

It is by no means so uncommon as might be imagined to find the air at the face of the workings and in the return air-courses of what are considered to be well-ventilated mines showing a cap at least ¼ inch high on the small oil-flame. I refer to my own observations in mines abounding in dry coal-dust, and reported to be *free from gas*, because no inflammable accumulation was known to exist in them at the time. In these cases the firedamp appears to be given off quietly at a uniform rate along the face of the coal, but nowhere in such quantity as to render the atmosphere locally inflammable. To give some notion of the volume of gas given off in this way, I need only mention that, in one instance, I found an air-current, whose volume amounted to 34,000 cubic feet per minute, showing a cap ¼ inch high. Taking this case as an example, we may suppose the amount of air to be doubled, so that where a cap ¼ inch high was to be found formerly there is now no trace of gas. Then we know that, so long as the coal-dust remains undisturbed, naked lights might be used with perfect safety; but let it once be raised and ignited by a small local explosion of firedamp, or by a shot such as that which caused the explosion in the Campagnac Colliery, and the final results may be of the most serious description. In this way some of the great explosions which have occurred in mines supposed to be almost, if not quite, free from explosive gas may perhaps be accounted for.

The explosion in the Campagnac Colliery might possibly have been partly due to the presence of a small proportion of firedamp in the atmosphere of the working-place in which it occurred. That place had been driven in coal to a distance of 25 metres beyond the ventilating-current of the district, and was ventilated only by an eddy which passed inwards along the floor and returned along the roof; and, although no firedamp had been found in it, the workmen were provided with a safety-lamp with which they were expected to make a careful examination before igniting a shot. This precaution was considered necessary, since slight explosions had taken place in other parts of the same mine. Lastly, the working-place was quite level, so that it offered no opportunity for an accumulation of explosive gas to be formed in it.

The most striking circumstance, however, connected with this explosion is that, although it raised a dense cloud of coal-dust along the gallery which formed the prolongation of the place in which it occurred, to a distance of from 130 to 150 metres, the flames do not appear to have extended more than 7 metres beyond the point at which they first encountered the ventilating-current.

Similarly, in the case of the Llan explosion, I found that, at a distance of 15 yards or so beyond the point where the principal air-current was met (*k*, fig. 2), the traces of coked coal-dust on the timber began to grow fainter; and although they could be found here and there to a distance of 70 yards further towards *e*, they were indistinct for the last 40 yards, and resembled sparsedly scattered grains of gunpowder. Let the plane on which figure 2 is described be elevated, so that the line *a c* dips towards *c* at an angle of 10° while $f\,O'''$ is level; then each line on the drawing represents a gallery about 8 feet wide by 5 feet high with solid coal on each side and rock above and below. $O'''f$ is the level referred to formerly; the roof had fallen so as to fill up most of the gallery (*h i*), and several of the places ($s\,s^1$ &c.) were also partially or wholly filled up. O is the only working-place shown; the others were in the pillars immediately above the level. All the galleries terminate as shown in the figure, except *a*, *b*, *c*, *d*, and *e*, which may be supposed to continue indefinitely. Bends of no consequence from our present point of view are omitted. Those galleries and parts of galleries in which traces of coked coal-dust were found are shown by means of plain lines, and the others by dotted lines. There was a *trap-door* in the gallery *a* and a *stopping* in *b* where the traces terminate; both were blown out; there was also a stopping at *g*. The arrow-heads show the direction in which the air was evidently travelling when the coke was deposited on the timbers.

Before leaving this part of the subject it may not be out of place to make a few remarks on the influence of blasting-shots in giving rise to explosions in mines. I have already had the honour of submitting a paper on the same subject to this Society, published in No. 154 of the 'Proceedings' for 1874. In that paper experiments were described which showed that an intense sound-wave, such as that originated by a blown-out shot, was able to pass the flame through the wire-gauze of a safety-lamp burning in an explosive mixture. The two hypotheses advanced in the reports of the Inspectors of Mines to account for the simultaneousness of explosions of firedamp with the firing of shots were also mentioned (p. 443); and I purpose again to refer to one of these, namely, that which supposes the firedamp to be ignited directly by the flame of the shot.

There can be no doubt that the gases which issue from a shot-hole have a sufficiently high temperature to ignite an explosive mixture of firedamp and air if they pass into it immediately. I exploded such a mixture of coal-gas and air many times by firing a pistol-shot into it when making experiments at the Meteorological Office in the beginning of the year 1873. It seems exceedingly doubtful, however, whether the gases even from a heavily-charged shot which blows out the tamping will retain a sufficiently high temperature to ignite a mixture of this kind at a distance of a few yards, if they have to pass through a space filled with pure air before reaching it. On the other hand, it may be reasonably supposed that if the same shot were fired in various mixtures of firedamp and air its flame would be prolonged more and more as these mixtures drew nearer to the explosive point, somewhat in the same measure as the cap on the flame of a lamp enlarges under the same circumstances. This prolonged flame might even partake of the nature of a local explosion of firedamp, especially if augmented by the presence of a small quantity of coal-dust, although those who fired the shot had not been able to discover the existence of any explosive gas beforehand. I undertook to investigate the nature of mixtures of gas and air which are not explosive at ordinary pressure and temperature, when I applied to the Government-Grant Committee for assistance in 1872; but I regret to have to say that, from various causes, I have not yet been able to carry out the necessary experiments.

M. Vital has given experimental results which tend to show that the flame of a shot is prolonged in a mixture of coal-dust and air. I have repeated his experiments with gunpowder, but without much success, having only once succeeded in getting the flame to appear at the end of the apparatus (fig. 3), when the shot was fired from a pistol in the position *p*; and as the mixture of coal-dust and air was travelling in the same direction at the rate of about 500 feet per minute, some deduction must be made on that account. The charge consisted of 1·365 gramme of gunpowder well rammed. I also placed a shield at O, and fired many shots through a hole in the centre into the current charged with coal-dust; the amount of gunpowder varied from 2½ grammes downwards, but on no occasion did the mixture seem to ignite.

It is always possible, however, that if coal-dust could be made fine enough, and were thoroughly mixed with dry air in the proportion of about 1 pound to 160 cubic feet of air, the mixture might be inflammable at ordinary temperature, or, if not, it might at least be so nearly inflammable that an explosion begun in it in a confined space might be propagated through it. Without some further proofs, therefore, it would be premature to draw any positive inference from my experiments with gunpowder-shots, as they are by no means so satisfactory as I could wish; and I am glad to be able to state that Professor Marreco, of Newcastle-on-Tyne, intends to investigate this question with more substantial apparatus.

The occurrence of three great explosions within as many days in the beginning of December last, seemed to indicate the influence of some external agency tending to produce the same result in each individual case. The barometer was high and the temperature at the surface exceptionally low at the time; and it is well known that these atmospheric conditions are not favourable to the occurrence of explosions in which firedamp alone is concerned. It had been often observed before that disastrous explosions happen most frequently during the winter months, and in some instances during very cold weather. Mr. Scott has recently informed me that he pointed out the latter circumstance in the year 1867 in an official letter to the Home Office; and in preparing the diagrams for our papers on the Connexion between Colliery Explosions and Weather, it was remarked by both Mr. Scott and myself that several great explosions had occurred in the years with which we had to deal (1868 to 1872 inclusive) during weather very similar to that which prevailed in the beginning of December last. This phenomenon was more marked, however, on the last occasion than at any time during my own experience; and while I was investigating the causes of the Llan explosion the following explanation presented itself to me, which I have now the honour of submitting to the consideration of the Fellows of this Society, with the remark that this part of the subject will be more minutely investigated by Mr. Scott and myself.

If we assume that the magnitude of some colliery explosions has been determined by the presence of coal-dust in the workings, and that the hygrometric state of coal-dust changes with the humidity of the air with which it is in contact, then it is an obvious conclusion that explosions of this kind will be most likely to occur when the air *in the mines* is driest; for at such times not only will the coal-dust be most easily raised into the air by the local explosion (which we may always suppose to happen at any rate), but it will also be burned more easily than when it contains a larger proportion of moisture.

As an example we may take the case of a dry mine, in which the temperature of the workings is 70° Fahr. During warm weather the air which descends the shaft has a temperature of, say, 60° when it enters the intake air-course; at this stage it is also saturated with vapour, for there is usually a little water trickling down the sides of a mine-shaft. The temperature rises gradually as the current draws nearer to the faces, and at length attains its maximum when the newly exposed face of the coal has been passed. During this process the humidity has also been increasing to some extent, always remaining below complete saturation, however, in a mine of this kind.

In very cold weather, on the other hand, the same current may sometimes have a temperature of 32°, or less, when it reaches the bottom of the shaft; and since it passes through the same workings, its temperature rises to 70° as before. It is plain, therefore, that, in the latter case, the ventilating-current must either obtain an additional supply of moisture from the workings (about $\frac{1}{2}$ pound for every 1000 cubic feet of air), or it must be *drier* than in the former case at every point of its course.

Primâ facie, then, this process of reasoning leads us to the conclusion that explosions *whose magnitude is due to the influence of coal-dust* will happen most frequently during cold weather; and, conversely, we might expect to find that the *magnitude* of those explosions which occur during cold weather is traceable, in some measure, to the influence of coal-dust.

The data represented graphically in figures 9, 10, and 11 are closely connected with this part of the subject: figs. 9 and 10 show the variations of temperature in the cabins at the bottom of Ferndale and

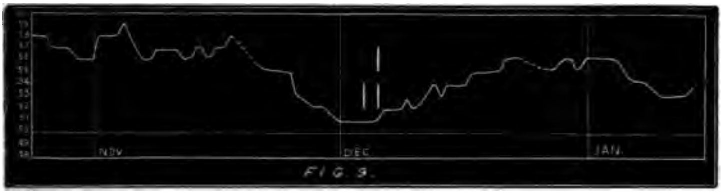


FIG. 9.

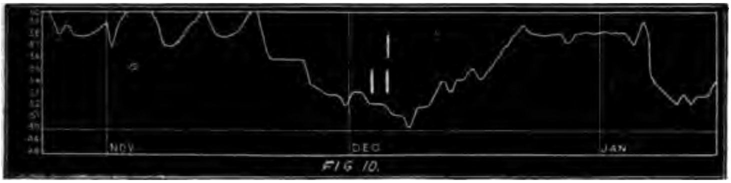


FIG. 10.

Figs. 9 & 10. Fires are kindled near the mouth of the Llwynypia downcast shaft to heat somewhat the air which enters it when its normal temperature is at or below the freezing-point. This is necessary in order to prevent the formation of large masses of ice on the walls, which would be the result if the numerous springs which percolate the brickwork were permitted to freeze for a considerable time. In this way the apparent irregularity of the temperature observed in the cabin of this mine at the beginning of December may be partly or wholly accounted for.

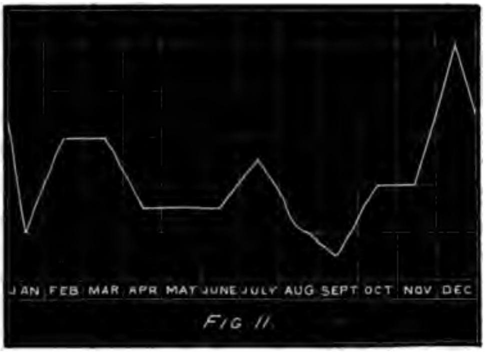


FIG. 11.

Llwynypia shafts, in the South Wales district, for six weeks before and after the explosions of the 4th and 6th of December last (these dates are marked above each curve by short thick lines); fig. 11 represents the numbers of great explosions which have occurred in each month of the year for the last twenty-five years (1851 to 1875 inclusive).

Ferndale and Llwynypia shafts are 286 and 380 yards deep respectively. The cabins, in which the observations of temperature are made daily, are small chambers 8 to 9 feet square by 7 to 8 feet high, formed in the coal on one side of a roadway. Each cabin is separated from the roadway by a brick wall with a door in it, which is usually kept shut. The door of the cabin in the Ferndale mine opens into the space between two trapdoors, in a passage which connects an intake with a return air-way. The side of the cabin on which the thermometer hangs is separated from the intake air-way by a thickness of 6 yards of coal; this point of the air-way is 130 yards from the bottom of the downcast shaft, and the current of air passing it amounts to 21,600 cubic feet per minute. The cabin in the Llwynypia mine is only 16 yards from the bottom of the shaft, and is situated at the side of one of the principal levels, where the quantity of air passing the door is about 30,000 cubic feet per minute.

The temperatures recorded in these two positions vary very little from day to day; and although they do not represent the actual variations taking place in the temperature of the ventilating-currents, they may be accepted, in a general way, as indices to the march of temperature in the intake air-courses. Regarding them only in this capacity, then, it is interesting to observe that, in each case, the temperature had reached a minimum about the end of the first week in December.

The great explosions which furnish the data for figure 10 are those by which nineteen, or more, men were killed; twenty was originally the lowest figure, but afterwards four others were included, by each of which nineteen men were killed. In consequence of this restriction the Llan explosion (17) is excluded, as well as many others of equal importance.

Arranging the months according to the number of explosions which took place in each, we have:—

December ..	10	October	4	June	3
February ..	6	November ..	4	January	2
March	6	April	3	August	2
July	5	May	3	September ..	1

The six months ending with March have produced thirty-two of these explosions, and the other six months only seventeen. January is exceptionally low among the winter months, a circumstance which may perhaps have some connexion with the general cessation of work for several days at the end of the year; and July is high among the summer months, indicating the effect of a high temperature at the surface in retarding the ventilation. The three explosions in May happened within the same fortnight in 1852 (May 6, 10, and 20); and September is particularly exempt, having only one.

It may be said in conclusion that the dangers arising from the presence of dry coal-dust in mines may be greatly diminished by having the coal-dust itself removed as far as possible, and extending the system of watering the roadways, now practised in many places for the sake of comfort. The same precautions are recommended in M. Vital's paper already referred to.

It should also be mentioned in this place that the ventilation of many mines will require to be largely augmented before we can reasonably expect to enjoy comparative immunity from the recurrence of explosions.

March 9, 1876.

Dr. GÜNTHER, M.A., Vice-President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

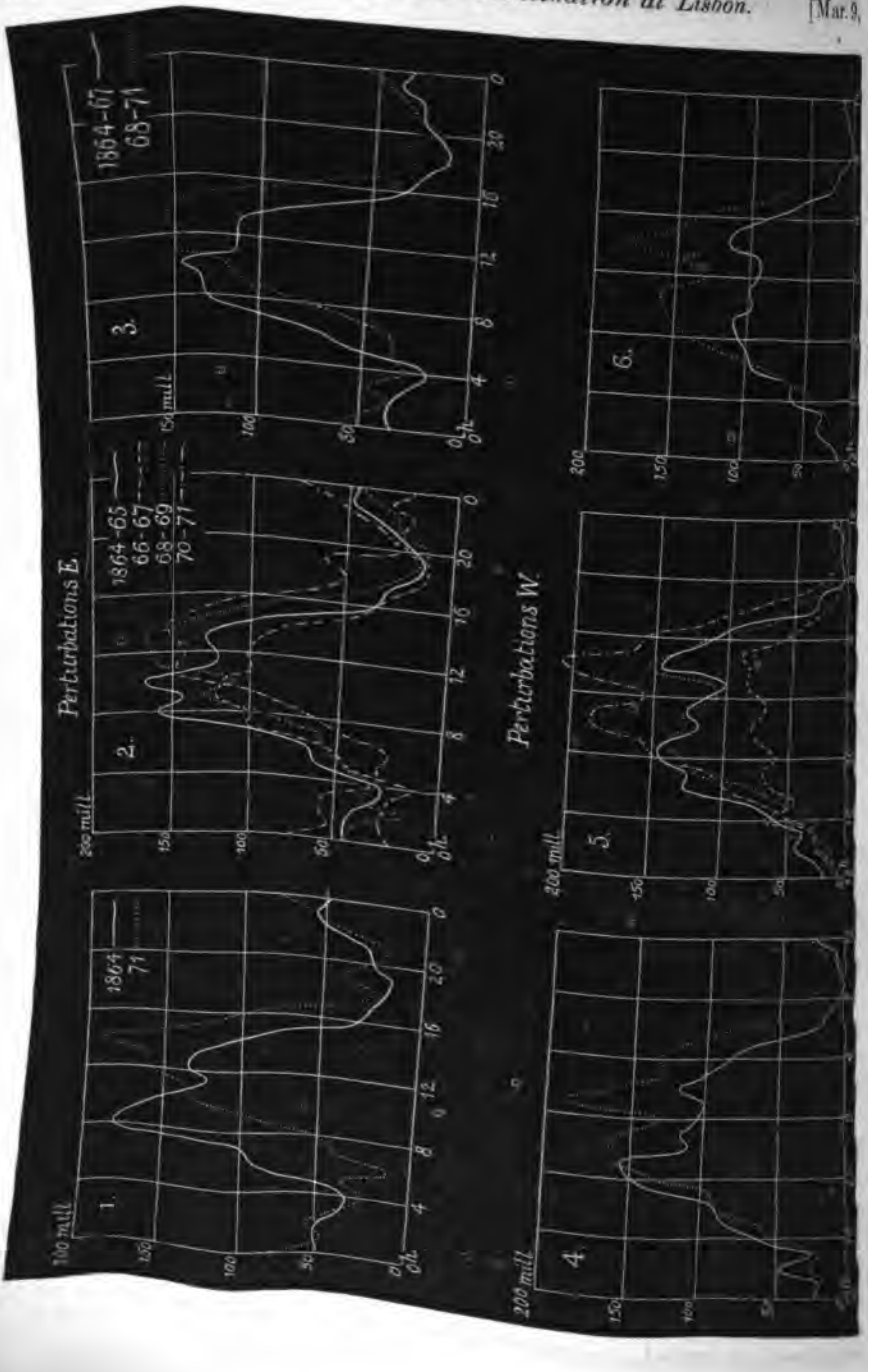
I. "On the Diurnal Variations of the Disturbances of the Magnetic Declination at Lisbon." By J. Capello, Director of the Lisbon Observatory. Communicated by Balfour Stewart, F.R.S., Professor of Natural Philosophy, Owens College, Manchester. Received February 12, 1876.

The Observatory of Infante D. Luiz has possessed since 1863 a set of magnetographs giving continuous records similar to those at Kew. In 1870 the results of the declination magnetograph, from the year 1864 to 1867, were published; and in 1874 the results for the same period of the bifilar and balance magnetographs (results embracing the horizontal force, vertical force, total force, and inclination) were published. At present the results of the declination for 1868 to 1871 are in course of publication.

The subject of this short paper is the diurnal variations of the disturbances of the declination. The method which has been adopted for reducing the disturbances is that of Sir Edward Sabine. I have taken ±2 millimetres, or 2′·26, as the limits, beyond which limits all readings are regarded as disturbed.

In separating for each hour the disturbances (that is to say, the excesses and the deficiencies of individual observations over the monthly means for each hour), and then taking for each year on one side all the excesses and on the other side all the deficiencies, we shall have a series of numbers in millimetres which represent the law of the frequency of these disturbances.

In comparing the curves which graphically represent the law of the frequency of the disturbances (+ West) and (− East) for the 8 years (1864 to 1871), it is at once noticed that all the phases appear later (as regards the hour of the day) for the latter years. In the easterly disturbances this tendency is manifested whether we make the comparison between the curves of 1864 and 1871 (fig. 1) or compare the curves for every 2 years (fig. 2), or finally the curves of the two periods of 4 years (fig. 3). In the westerly disturbances similar results are found, but they are less marked; the movement appears to be slower; and it is in


Perturbations E.
1.
1864
71
100 mill
150
100
50
0
0h
4
8
12
16
20
0
2.
1864-65
66-67
68-69
70-71
200 mill
150
100
50
0
0h
4
8
12
16
20
0
3.
1864-67
68-71
150 mill
100
50
0
0h
4
8
12
16
20
0
Perturbations W.
4.
200 mill
150
100
50
5.
200 mill
150
100
50
6.
200
150
100
50

these disturbances more difficult to prove it on account of the close double maximums which show variations from one year to another*.

However, it is easy to see, in either of the figs. 4, 5, or 6, that the dotted curves are generally displaced to the right of the plain. This difference in behaviour between the easterly and westerly disturbances still tends to support the supposition of their different sources. It is very probable that these movements are periodical.

The staff at the Observatory who can be engaged in measuring the photographic curves of the magnetograph, and making the calculations upon the monthly tables, is at present engaged with the curves of the bifilar and balance magnetographs for the years 1868 to 1871.

It would be very interesting to know if similar displacements in the disturbance-curves at the stations in Asia and America have been observed, and in what direction.

The following Table gives the total of the disturbances of the declination:—

	West. millims.	East. millims.	East and West. millims.
1864..........	1666·3	1797·4	3463·7
1865..........	1970·6	1598·4	3569·0
1866..........	1313·4	1382·6	2696·0
1867..........	832·1	1164·5	1996·6
1868..........	1635·0	1514·7	3149·7
1869..........	1784·9	1755·8	3540·7
1870..........	2486·0	1813·3	4299·3
1871..........	2045·4	1734·1	3779·5
	13733·7	12760·8	26494·5

Thus near 1870, or a little after, there is a maximum period of disturbances, and from 1866 to 1867 there is a minimum period of disturbances, agreeing with the observed periods for the maximum and minimum of sun-spots.

II. "On the Development of the Crustacean Embryo, and the Variations of form exhibited in the Larvæ of 38 Genera of Podophthalmia." By C. Spence Bate, F.R.S. Received December 28, 1875.

(Abstract.)

The author states that, although the general forms of several genera of Podophthalmous Crustacea are known, yet the details of their structure have been so unsatisfactorily figured and described, that the value and importance of hereditary elements are incapable of being studied and appreciated.

---

* It is observed that the hollow between the two maximums about noon corresponds closely to another secondary maximum of the easterly disturbances. It thus appears that, during the hours 20 A.M. to 3 P.M., there is another force in action independent of the two principal forces.

Through Dr. Carpenter he received from Mr. Power an offer of a considerable number of larvæ of exotic species, together with the parents from which they had been obtained; in relation to which Mr. Power wrote:—

"Dear Sir,—I have to thank you for your kindness in answering my letter to Dr. Carpenter, and for the memoirs.

"My collection of Crustacea and the microscope-slides of the larvæ are at present, and have been, packed up in Fort Louis. Now I am again on detachment; and if left here in peace for a few months, I shall arrange my specimens and finish up the microscopic drawings.

"All my larvæ are hatched in basins (the only kind of aquaria my nomad life allows me to use), so each crab or prawn &c. whose larvæ I possess is identified with its young; and this reminds me that on reading Fritz Müller's paper in the 'Annals' (1864, vol. xiv. p. 104), I was much astonished, as none of the prawns or prawn-allies whose young I have hatched show any such *Nauplius* form as shown in figures 1 & 3, &c.; but all I have observed as yet are born like fig. 8, or near it.

"I have been quite unable to rear any crab-larvæ beyond a day or two after birth; whether they require moving water or not I do not know; but certainly, though I have kept the parents alive for several weeks in basins (the water changed once or twice in 24 hours) of salt water, the same method would not succeed with the larvæ. I then tried small aquaria, and signally failed again.

"I have not been in the neighbourhood of fresh water as yet, so have had no opportunities of observing the freshwater Crustacea, though there are a good many crab and shrimp forms. I have found two kinds of that curious parasitic crustacean which adheres like a little polypus, a mere bag with a peduncle, but containing hundreds of young Crustacea whose genus I do not know, as I cannot find any account of them in Van der Hoeven's 'Zoology'*.

"If I succeed in getting posted to one of the regiments here, my life will be more stationary, and I shall have far better chances of working my crab-hatchings.

"In Fritz Müller's paper before referred to, I fancy that he has not hatched the different larvæ mentioned. After reading the paper very carefully, I could not help fancying that the various stages of development were not hatched through, but specimens were captured at different times, and perhaps larvæ of totally different species have been given as stages of the same animal. I say this with great doubt; but reading the paper will, I think, bring every one to the same conclusion. Thus he says, 'the unaltered *Nauplius* form, probably the same in which the animal escapes

---

[* New genus allied to *Sacculina*, which hatch larvæ in the cirriped pupa stage.—C. S. B.]

from the egg, came under notice only once;' again, 'This larva (taken on the 13th of January) is closely approached by four others, probably *belonging* to the same swarm, which were taken at the same time (24th January);' and so on.

"To tow a net in these tropical seas and to examine all the microscopic Crustacea would give a most extraordinary assemblage of forms; but I doubt if it is so useful as tracing the steps of individuals.

* * * * * * * *

"I have not yet hatched the land Hermit-crabs, though I suppose they are much as the ordinary sea specimens, and they certainly spend their larval life in the sea.

"Pray excuse my rambling letter, and please let me know of any way in which I can be of any use to you in my humble dips into natural history.

"Yours very truly,
"WILMOT HENRY POWER,
"*Staff-Surgeon, 44th Regt., Lt. Inf.*"

Some time afterwards the author received the promised collection, together with Mr. Power's drawings and notes. These have enabled him to identify the parent forms of some known larvæ, and also to determine those of several unknown genera.

It has also led him to the conviction of a unity of character throughout the various forms and changes of Crustacea; that variety in form is never inconsistent with homological truth; that parts suppressed or rendered abortive for want of use are never absolutely lost, and may be reproduced under conditions that may require them.

The eyes of those Crustacea, such as *Alphæus*, that inhabit dark places are reduced in power according to the condition of their habitat. But these organs are, in their larval state, as well developed, if not more so, as any of those whose life is passed in the bright sunshine of the surface of the ocean.

The blind *Didamia* brought from the depth of four miles below the surface of the Atlantic by the dredges of the 'Challenger' differs in no respect from *Polycheles*, taken by Heller in the comparatively shallow Adriatic sea. In the blind prawn from the Mammoth Cave of America, and the sightless *Nephrops* of Formosa, the organs of vision are reduced to the smallest condition consistent with their retention; and in the Cirripedes the eyes are represented by their nervous apparatus only.

The several forms of larva have not, in the prawn-allies, shown any approach to the *Nauplius* state, as mentioned by Fritz Müller, so that the author believes that it must be confined to the genus *Penæus* alone among the Podophthalmia. Nor should it be forgotten that the *Nauplius* form has only been observed as a free-swimming animal.

The author has taken this opportunity of making a close examination into the earlier stages in the development of the embryo, and comparing the progress within the ovum of some of the larvæ that arrive at or near maturity before being hatched, with those of the larval forms that are hatched in a more immature condition; and he states that, as soon as the protoplasm assumes any thing like a definite plan, distinct lobes, corresponding in position with those of the several appendages in the *Nauplius*, together with an embryonic or ocular spot, are present; that in the *Nauplius* forms they exist as deciduous appendages only, and are soon cast aside and replaced by others more adapted to the wants of the adult existence.

In the embryos of other Crustacea the anterior pair of lobes enlarge in size with little alteration of form, while the posterior two pairs are developed into appendages that have but a deciduous value, since they never fulfil the office of permanent organs, and are generally cast off with an early moult.

This is observable within the ovum in *Palæmon*, *Crangon*, &c., and also in the marsupial embryo of *Mysis* after it has quitted the ovum.

The relation of these parts to the permanent organs the author has closely traced, and believes that he has demonstrated that the three pairs of mobile appendages in the cirripedal or *Nauplius* form of larva homologize with the eyes and two pairs of antennæ, and not with the antennæ and mandibles, as stated by Fritz Müller, Anton Dohrn, and others.

The author, moreover, contends that the small pair of filamentary appendages seen on each side of the ocular spot, existing in the *Nauplii* of Cirripedes, homologize with the peduncular appendage existing in the larva of *Caligus*, the arm-like appendages in the pupa-stage of Cirripedes, the peduncle of the stalked Cirripedes, and probably also with the long multiarticulate, antenna-like organs belonging to the fossil *Pterygotus*.

He also demonstrates the origin of the nerves in a mass of cellular material that reaches from one extremity of the embryo to the other. This divides into parts corresponding to the various somites into which the animal divides. These masses gradually separate from each other as the animal increases in size, and concentrate into the several ganglia that form the great nervous chain.

The author also shows the origin of the permanent organs of vision, and the manner in which the number of lenses increases with the growth of the animal, and traces the origin of several of the internal viscera and their mode of growth.

He also figures, in minute detail, the larvæ of the following genera (those in *italics* are from British specimens, while all the others are from the collection sent to him by Mr. Power):—

Palæmon fluvialis, n. sp.
—— *squilla*, Leach.
Crangon vulgaris, Leach.
Hymenocera, *Heller*.
Alphæus obesimanus, *Dana*.
Homaralphæus, n. g.
Homarus marinus, Leach.
Palinurus vulgaris.

Astacus fluviatilis.
Squilla.
Porcellana rugosa.
—— *longicornis.*
Galathea.
Pagurus tibicen.
—— elegans.
—— Bernhardus.
Clibinarus.
Trichia.
Gelasimus.
Cyclograpsus.
Libinia.
Mensætheus.
Stenorhynchus.
Mithrax.
Trapezia pectinata.
—— ferruginea.
Pilumnus.
Melia tessellata.
Carpelodes rugipes.
Actinurus setifer.
Xantho Lamarckii.
Actæa obesa.
Thia ?
Liomera.
Pirimella ?
Thalamita.
Achelous.
Euriphia.
Thalassina.
Carcinocystus, n. g.

III. "On a Secular Variation in the Rainfall in connexion with the Secular Variation in amount of Sun-spots." By CHARLES MELDRUM, M.A., Director of the Mauritius Observatory. Communicated by B. STEWART, F.R.S., Professor of Natural Philosophy, Owens College, Manchester.

(Abstract.)

In this paper the author sums up the principal results obtained by his investigations as follows:—

(1.) Taking for the individual years of maximum and minimum sun-spot those given in par. 4[*], it is found that the rainfall in the maxima exceeds the rainfall in the minima years in each country or district, and therefore in all taken collectively, the mean annual excess for Great Britain being 1·94, for the continent of Europe 3·64, for America 5·17, for India 8·98, and for Australia 6·23 inches, which gives a mean excess of 5·19 inches. In Great Britain the rainfall in seven of the nine years of maximum sun-spot exceeds the rainfall in the corresponding seven out of nine years of minimum sun-spot; on the continent of Europe six out of seven maxima years are similarly favourable; in America five out of six are favourable, in India four out of six, and in Australia two out of three.

A comparison of the mean rainfall of all the stations taken collectively gives an average annual excess of 7·01 inches in favour of the years of maximum sun-spot, and seven of the nine maxima years are favourable.

(2.) It is thus seen that the excess is not owing to abnormal and casual heavy falls in one or two years of maximum sun-spot, but that it is evidently the result of law; for the years of most sun-spots are the rainiest years *generally* in every part of the world the rainfall of which has been obtained for a sufficient number of years.

---

[*] Namely:—Years of maximum sun-spot, 1729, 1739, 1750, 1761, 1770, 1778, 1789, 1804, 1817, 1829, 1837, 1848, 1860, 1871; years of minimum sun-spot, 1733, 1743, 1756, 1766, 1776, 1785, 1798, 1811, 1824, 1834, 1843, 1856, 1867.

(3.) By taking three-year maxima and minima periods, and comparing their rainfall, it is found that an increase of rain from the minimum to the next maximum period, and from the maximum to the next minimum period, is the general rule, with a few local exceptions, almost all of which disappear when means of all the observations are taken. Thus we find that 95·7 per cent. of the three-year maxima and minima periods are favourable in Great Britain, 75·0 on the continent of Europe, 88·8 in America, 88·2 in India, and 87·5 in Australia, &c., giving a favourable mean percentage of 87·0.

(4.) Taking the annual mean rainfall of the five districts collectively, the percentage of favourable maxima and minima periods is 91·3, showing that there is scarcely any exception to the law of increase of rain in the years of maximum, and decrease of rain in the years of minimum sun-spot. This fluctuation is well seen in the Tables containing the annual mean rainfall of the *globe* (that is, of all the stations), the rainfall of each of the triennial periods being given separately. Of the nine wettest and the nine driest years 77·8 per cent. are within two years of the epochs of maximum and minimum sun-spot.

(5.) A large majority of the entire sun-spot periods are also favourable. This is shown by taking the annual rainfall at the same stations for each period, placing the rainfall in the years of minimum sun-spot at the beginning and end, and the rainfall in the years of maximum sun-spot in the middle of the period, and observing whether the rainfall first increases and then decreases. Of the number of entire sun-spot periods, 78·6 per cent. are completely favourable, and some others partially favourable, making the favourable percentage still greater.

(6.) When the years of greatest and least rainfall occur within two years of the years of most and least sun-spot respectively, they are considered favourable, and unfavourable when they fall beyond these limits. From this point of view, we have for Great Britain 72·2 per cent. of the wettest and driest years favourable, for the continent of Europe 57·1, for America 66·7, for India 83·3, and for Australia also 83·3, giving a mean percentage of 72·5. The mean rainfall of all the stations (globe) gives a favourable percentage of 77·8.

(7.) With respect to the rivers, the results, as might be expected, are similar. The depths in the maxima exceed the depths in the minima sun-spot years by an annual average of 16·2 inches (Austrian); and of thirteen maxima years, compared with thirteen minima years, there are only three in which the excess is not in favour of the former. As to the maxima and minima triennial periods 79·4 per cent. of them are favourable, the rivers, as a rule, rising and falling with the amount of sun-spot. Of the thirteen entire sun-spot periods 77 per cent. are favourable. Of the fifteen years in which the depths were greatest 60 per cent. were within two years of maxima sun-spot years, and 61·5 per cent. of the years in which the depths were least were within two years of minima sun-spot years. The latter percentages, although favourable, are less so than those for the rainfall, owing to obvious causes.

(8.) All the above results have been obtained by strictly adhering to the adopted years of maximum and minimum sun-spot, and by taking the absolutely wettest and driest years, however little the rainfall in them might differ from that of other wet and dry years in their neighbourhood. It is clear that this was subjecting the hypothesis to a severe test; for there is some doubt as to the positions of the years of maximum and minimum sun-spot, especially in the earlier periods of observation; and, assuming a connexion between rainfall and sun-spots, it might well happen that the absolutely wettest and driest years would not always, or even often, fall within two years of the epochs of maximum and minimum sun-spot. The results, therefore, may be considered highly favourable; but they become still more so if, in a few cases, the epochs of maxima and minima be altered to the extent of *one* year, and if, for the absolutely wettest and driest years, almost equally wet and dry years be occasionally substituted. A slight alteration of this kind would, for instance, raise the percentage of favourable maxima and minima periods on the continent of Europe from 75 to 100, and make *all* the wettest and driest years favourable. Similar results would be obtained for the other districts of observation.

(9.) The ratios of the maximum and minimum rainfall to the mean rainfall (especially the latter ratio) are nearly the same for each part of the globe; and this points to the sun as the main agent in producing rainfall variation. The ratios of the maximum and minimum river-depths to the mean depth are almost the same as those for the rainfall.

(10.) The years of maximum and minimum sun-spot are characterized by great rainfall and river oscillations, a circumstance which also points to the sun as the disturbing cause *.

(11.) As the mean duration of the sun-spot period is 11·1 years, while the interval from the minimum to the maximum is about 3·7 years, and from the maximum to the minimum about 7·4 years, the durations of the rainfall and river cycles, and the intervals between their epochs of minima and maxima and maxima and minima, should approach those for the sun-spot cycle, supposing that the three cycles are connected by a common cause. Now this is found to be generally the case. The intervals between the consecutive wettest and between the consecutive driest years for Great Britain are 11·3 and 10·8 years respectively, while the interval from the driest to the wettest years is 3·9, and from the wettest to the driest years 6·8 years. For the continent of Europe the mean duration of the period is 11 years; but the intervals are less favourable, being 5·3 years from the driest to the wettest, and 5·2 from the wettest to the driest. The results for America are nearly the same. In India the mean duration of the period is 10·8 years, the mean interval from the driest to the wettest years 4·5, and from the wettest to the driest 5·8 years. For Australia we get a mean period of 10·7 years, with an interval of 4·7 from the driest to the wettest years, and of 5·5 from the wettest to the driest years. The means of the five results are as follows:—Duration of period = 11 years; interval from driest to wettest years = 4·8 years; interval from wettest to driest years = 5·8 years.

---

* The greatest river-fluctuations occur in minima years.

The mean rainfall of the globe (all the stations) gives the following results:—Mean duration of period = 10·6 years; mean interval from driest to wettest years = 4·9 years; mean interval from wettest to driest years = 6 years.

For the river-depths the mean duration of the period is 11 years; the mean interval from minimum to maximum 3·8, and from maximum to minimum 6·8 years.

(12.) The results just given are of course only approximations. They were, however, considered so favourable as to encourage a closer examination; so that whenever I procured a portion (at least) of the Kew values of the sun-spot area, and of Wolf's relative numbers, I compared the former with the rainfall from 1832 to 1867, and the latter with the rainfall and river-depths for the longest possible periods, and on the whole obtained very favourable results.

(13.) Supposing (as Mr. J. Allan Broun does) that any connexion that may subsist between sun-spots and rainfall may be approximately represented by the equation $\Delta R = f \Delta A$, it is found that the values of f for Great Britain, the continent of Europe, America, India, and Australia from 1832 to 1867 are all favourable, except for America, where it is slightly unfavourable.

(14.) There are, apparently, some discrepancies between the Kew values and those of Wolf for the period 1832–67. For when, in place of ΔA (difference of sun-spot area from the mean) we take Δr (difference of Wolf's relative numbers from the mean), we obtain favourable values of f for *all* the five districts.

(15.) A comparison of Wolf's relative numbers with the rainfall of each country for the longest possible periods also gives very favourable results. The agreement of ΔR and δ with Δr, in regard to the signs (+) and (−), is remarkable, especially for the period 1842 to 1872, during which the rainfall of a portion of the southern hemisphere is represented. The values of f in the equation $\Delta R = f \Delta r$ are favourable for each country, and (taking all the stations) they are also favourable for each of the seven sub-periods, except the one 1832–41. The whole period of 77 years gives for the rainfall of the globe $\Delta R = + \cdot 05745 \Delta r$; and from this equation we obtain a mean annual difference of 5·03 inches in favour of the years of maximum sun-spot.

(16.) A similar comparison of Δr with ΔD (differences of river-depths from the mean) also gives favourable results. The 116 years of river-depths (1756 to 1871) compared with the relative numbers of sun-spots for the same years give the equations $\Delta D = + 0{\cdot}17322\ \Delta r$ and $\Delta D = + 0{\cdot}12266\ \Delta r$. According to these equations the depth in the years of most sun-spot should exceed the depth in the years of least sun-spot by an annual average of 12·69 inches. For all, except three, of the 11 sub-periods into which the 116 years are divided the values of f are favourable, and they would no doubt be found favourable as far back as the observations of river-depths extend (1728), if we had the sun-spot numbers for those years.

(17.) Sun-spot, rainfall, and river curves laid down from the Tables have, notwithstanding some exceptions, a general resemblance, which cannot, I think, be ascribed to chance. The resemblance, as might be expected, is greatest in the case of the rainfall curve for the globe. Here, with the exception of two or three years in the period 1765 to 1776, for which there are only three stations, and of three years in the period 1832 to 1841, the resemblance is very strong.

(18.) Of the seven entire sun-spot periods of rainfall for the globe, the mean values of six can be compared with the mean values of Wolf's relative numbers by placing the maxima years near the middle and the minima years at the beginning and end of each period, so as to have nearly all the maxima years in one horizontal line, and the minima years in other horizontal lines. This is done in one of the Tables. The river-depths for the same six periods are similarly arranged in another Table. Then, applying Bessel's formula, we get three equations, the second terms of which enable us to lay down three curves showing the general progression of sun-spot, rainfall, and river-depths. The modification of these curves by the third terms of the equations is shown by dotted curves. In a similar way we obtain three other equations and curves for five sun-spot periods, in which the minima years of sun-spot are placed near the middle and the maxima years at the commencement and end. The resemblance of the curves to one another is very striking.

(19.) According to the terms containing θ and $2\,\theta$ in the first three equations the three cycles have nearly the same lengths. The rainfall maximum occurs 4·8 months *after* the sun-spot maximum, and the river maximum 9·6 months after the rainfall maximum. According to the second three equations the rainfall minimum occurs 10·8 months *after* the sun-spot minimum, and the river minimum 3·6 months *after* the rainfall minimum. The mean range of rainfall variation is 6·19 inches, and of river-depth variation 16·73 inches. The intervals from the minima to the maxima epochs are in every case less than those from the maxima to the minima epochs, and the ratios of the former to the latter intervals are nearly the same for all the three cycles.

(20.) These results will be somewhat modified by the fourth and fifth terms of the equations and by additional observations; but at present they may be considered fair approximations. The mean excess of rainfall (6·19 inches) is almost the mean of the 5·19 and 7·20 inches previously obtained, and the 16·73 inches of river-fluctuation are nearly the same as the 16·20 inches found by taking the means of the depths in the adopted maxima and minima years. The durations of the periods, and the intervals from minimum to maximum and from maximum to minimum, given by the equations are also not very different from those given directly by the observations.

(21.) Although the mean depths of the rivers have apparently been decreasing, yet the range of variation has altered little. It would thus appear that there is some general cause which operates irrespectively of local causes, and that its effects usually override all other effects. This is shown by the differences between the greatest and least depths for consecutive periods of ten to thirteen years.

The more numerous the observations the more evident does a connexion between sun-spots and rainfall become. At first (1872) the rainfall at only three stations (Mauritius, Adelaide, and Brisbane) was examined. To these Mr. J. Norman Lockyer, in a paper "On the Meteorology of the Future" ('Nature,' vol. vii. p. 142), added the rainfalls of the Cape and of Madras, strongly expressing in favour of the hypothesis (even at that early stage) an opinion which, though not then accepted by some meteorologists, all subsequent investigations, including those of Mr. Blanford, Prof. Broklesby, Mr. Dawson, Mr. Ellery, Dr. Jelinek, Mr. R. H. Scott, and Mr. Symons, have amply justified*. The number of stations has, in short, gradually risen from three to 144, and the results of each successive investigation have been an improvement on their predecessors.

Not only has the number of stations been increased; the periods of observation have been greatly extended. At first we had only ten to forty-five years' observations, comprising at the utmost one to four sun-spot periods. We have now rainfall observations for seven and river-observations for thirteen sun-spot periods; and the fact that the law holds good with the earlier as well as with the later observations is significant. The variations in the level of the Elbe, from 1728 to 1777, followed the sun-spot variations as regularly as those of the rainfall and rivers have done in later times.

The amount of rainfall variation is greatest within the tropics, and seems to decrease as the latitude increases. This is a point, however, which requires further examination by considering the observations belonging to different zones. The positions of the belts of calms and variables may be found to have a secular variation.

---

* I have not seen Prof. Tyndall and Mr. Hennessy's contributions.

It is to be borne in mind that the average excess of rainfall in the maxima years (6·19 inches) is obtained by taking all the observations of whatever description. Most of the observations are favourable, but others are unfavourable. If the former alone had been taken, the excess would be much larger. Now the rainfall at many of the stations seems to be permanently favourable, while at several others it seems to be permanently unfavourable*; that is, there are many stations at which the rainfall is invariably, or at least generally, greater in the maxima than in the minima years, while at some others the reverse takes place. As a rule, it would appear that the stations near the sea and fully exposed to winds sweeping over a considerable expanse of water are favourable, while the unfavourable ones are those exposed to winds passing over land and liable to be deflected by mountains and valleys. Bombay, Madras, Mauritius, Cape of Good Hope, Brisbane, Melbourne, Plymouth, and Charleston (U.S.) are among the favourable stations, and Calcutta, Milan, and Trieste amongst the unfavourable. At Bombay (exposed to the S. W. monsoon) there has been only one exception to the general law since 1817, and at the Cape of Good Hope, Mauritius, &c., as far as observation extends, there has been no exception at all. On the other hand, Milan furnishes an opposite example. What we have to do, then, is to separate the favourable from the unfavourable stations, and to study the rainfall of each class by itself. The *total* rainfall of the globe generally is about 6 inches greater in the maxima than in the minima sun-spot years; but there are local exceptions, and it is important to know their laws.

As the rainfall at a majority of stations fluctuates with the sun-spots, and as the amount of fluctuation for these stations is considerably greater than 6 inches, it would probably be of advantage to be able to predict the epochs of maximum and minimum sun-spots. Dr. De La Rue and Prof. Balfour Stewart have shown that the sun-spots are, to some extent, connected with the relative positions of the planets and sun. If, then, it were proved that the sun-spot period depends upon the configuration of the planets, and the rainfall period on sun-spots, it would be easy to predict the general character of the seasons for large portions of the globe. Even without this it is possible, as recently pointed out by Mr. Ellery, in his Annual Address to the Royal Society of Victoria, that there is so much interdependence in the rainfalls of different countries, that, with our present knowledge and with the aid of the telegraph, we may shortly be in a position to foretell whether a coming season is likely to be a wet or a dry one. The results of the present investigation warrant the inference that, generally, the rainfall of the next two or three years will be below the average rainfall of the years 1870–3, and that, though some places may suffer from floods, more will suffer from drought. From all the information I have been enabled to collect, it is not improbable that the rainfall of this year (1875), remarkable though it is for destructive floods in various parts of the world, will be less than the average. Floods are, apparently, characteristic of the setting in of the minimum period of sun-spots, especially on the continent of Europe. But these floods are local, and the large vintage in Central Europe is an indication that, generally, the rainfall there for at least several months of the year has not been excessive.

---

* These are few in number. Observations for long periods show that the law of fluctuation holds good at a great majority of stations.

A completely satisfactory proof of a connexion between sun-spots and rainfall requires that the variation in the rainfall must necessarily follow from the variation in the sun-spot area. We may show that the two periods, as far as observation extends, are equal, that the intervals between their maxima and minima epochs are equal, and that the times of the epochs themselves are exactly what might be expected. It might also be argued that periodic constitutional changes in the sun, as indicated by the solar spots, must produce atmospheric changes. But granting all that, it may be said that so long as there is a bare possibility of explaining the phenomena otherwise, the evidence is incomplete. There may be two independent causes at work, one producing a sun-spot and the other a rainfall cycle, and the two causes and effects may have run nearly parallel to each other for many years; but it does not follow that they will always do so.

Such a possibility may exist, but it seems to be a rather remote one; and in order, if possible, to make it still more remote, it may be desirable to compare the amount of sun-spots and rainfall for each day and month.

But supposing it were fully established that the rainfall and sun-spot variations are produced by one and the same cause, it may be asked whether the corresponding eleven-year period of magnetic variation, discovered by Sir Edward Sabine, has also the same cause; and if so, by what process are such apparently dissimilar effects as rainfall and magnetic variations produced by a common agent? I would hazard the opinion that the proximate cause of the sun-spot, magnetic, and rainfall cycles is a secular variation in the intensity of solar heat, the solar spots or cyclones being, like terrestrial cyclones, most frequent when the temperature is greatest, that the sun radiating more heat in some years than in others evaporation and rainfall are greater in the former than in the latter, and that the changes in solar radiation affect the earth's magnetism. This opinion seems to receive some support from the circumstance that, according to some remarks recently made by Sir George Airy at a meeting of the Institution of Civil Engineers, and to researches by Mr. Blanford ('Nature,' vol. xii. p. 188), solar radiation is greater in the rainiest years, that is, in the years of most sun-spot. That the rainiest years should be the years of greatest solar radiation, is, as was argued in a paper read before the Meteorological Society of Mauritius on the 16th of January, 1873, what analogy would lead us to expect.

March 16, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Preliminary Reports to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work done on board the 'Challenger.'" By John Murray, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

II. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Staff, on the true Corals dredged by H.M.S. 'Challenger,' in deep water, between the dates Dec. 30th, 1870, and August 31st, 1875." By H. N. Moseley, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

III. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Observations made during the earlier part of the Voyage." By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

IV. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Crustacea observed during the Cruise of H.M.S. 'Challenger' in the Southern Sea." By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

V. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work (Chemical and Geological) done on board H.M.S. 'Challenger.'" By J. Y. Buchanan, Chemist and Physicist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received March 7, 1876.

[These Reports will appear in a subsequent Number of Proceedings.]

March 23, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Force caused by the Communication of Heat between a Surface and a Gas, and on a New Photometer." By Prof. Osborne Reynolds. Communicated by B. Stewart, F.R.S., Professor of Natural Philosophy in Owens College, Manchester. Received February 24, 1876.

(Abstract.)

This paper contains an account of an experimental investigation undertaken with a view to support, by absolute measurements, the theoretical arguments by which the author endeavoured to prove the existence of reactionary forces or "heat-reactions" whenever heat is communicated from a surface to a gas, and *vice versâ*, and the connexion between these forces and the motion caused by heat and light falling on bodies *in vacuo*.

Since the publication of the author's paper on this subject in the 'Proceedings' for April 1874, the correctness of his conclusions with regard to the existence of these heat-reactions has not been controverted or even questioned; while Professors Tait and Dewar, after an elaborate investigation, entirely confirm the author, not only in these conclusions, but also in his view as regards the explanation of Mr. Crookes's experiments. Mr. Crookes, however, appears entirely to repudiate this explanation, arguing,—

1. That he obtains his best results in vacua so perfect that there is no air either to receive the heat or react on the surface.

2. That the force is *radiant* in character.

3. That light, as well as heat, produces the motion, which consequently cannot be due to the heating of the surface.

Having obtained one of the beautiful little "light-mills" constructed by Dr. Geissler, of Bonn, the author was in a position to make quantitative measurements of the effects produced and of the force producing them.

In the first place, with regard to the sufficiency of the residual air to cause the motion. It was found that this air is, with the exception of the friction of the pivot, which is found to be so small as to be inappreciable, the sole cause of the resistance which the mill experiences, of the limit which is imposed on its speed for each intensity of light, and of the rapidity with which it comes to rest when the light is removed. The law of resistance, as determined by careful measurements, is found to agree perfectly with the resistance which highly rarefied air would offer to its motion; and this law is distinctly special in its character, being proportional to the velocity at low speeds, and gradually tending towards the square of the velocity as the speed increases.

Having established the fact that there is sufficient air in the mill (and Mr. Crookes's behaves in the same manner as this mill) to balance, by its resistance, the force which moves the mill, it is argued that all question as to the sufficiency of the air to cause the forces is removed. What the air can prevent it can cause.

As regards the possibility of the motion being in any way the direct result of radiation. This supposition the author had previously shown to be directly contradicted by the fundamental law of motion that action and reaction are equal. A cold body runs away from a hot body, while, if free to move, the hot body will run after the cold body, showing that the force does not act from body to body, but that each body propels itself through the surrounding medium in a direction opposite to its hottest side, the effect of one body on the other being due solely to the disturbance which it causes in the equilibrium of temperature.

The truth of this view was entirely confirmed by an experiment made by Dr. Schuster, to be communicated to the Royal Society. Dr. Schuster, by suspending the entire mill, was able to see whether the force which causes the vanes of the mill to revolve caused any twisting force on the envelope; and he found that such twisting force, so far as it existed, was exactly what must result from a force arising entirely within the mill, *i. e.* between the vanes and the medium immediately surrounding them. While the vanes were acquiring momentum a reaction was experienced by the envelope; but when the vanes had acquired full speed, the envelope was subjected to no force whatever; when, however, the light was turned off, the vanes, by virtue of the friction they experienced, tended to drag the envelope with them.

Besides proving that the force acts between the vanes of the mill and the medium immediately surrounding them, Dr. Schuster's experiments furnish a quantitative measure of the actual force. Taking the manner of suspension and the weight of the mill into consideration, the effect produced showed that, when making 240 revolutions per minute, the torsional force on the vanes does not exceed one forty millionth part of a pound acting on a lever a foot long; that the pressure of the gas on the vanes to produce this was not more than one two million five hundred thousandth part of a pound on the square inch, or one thousandth part of the pressure in a Torricellian vacuum, thus placing the extreme minuteness of the forces in a clear light, a light from which the extreme delicacy of Mr. Crookes's instrument had altogether withdrawn them.

It is then shown on theoretical grounds that the difference of temperature on the two sides of the vanes necessary to cause heat-reactions of this magnitude could not be less than 1°·7 F., while the probability is that it is considerably more.

In order to apply this test and see how far the actual difference of temperature in Dr. Schuster's experiments corresponded with that deduced from the theory, a new photometer was devised by the author with an immediate view of measuring the difference of temperature caused by light on a black and a white surface.

Of two thin glass globes, 2½ inches in diameter, connected by a siphon-tube ⅛ inch internal diameter, one was blackened with lampblack on the inside over one hemisphere and the other was whitened with chalk in a similar manner, the two clean faces of the globes being turned in the same direction. Oil was put in the tube and the globes were otherwise sealed up. Any light which enters through the clean faces is received on the black and white surfaces, and the air in the globes expands in accordance with the difference of temperature which they attain, moving the oil in the tube. A motion of ½ an inch on the part of the oil shows a difference of 2°·2 in the temperature of the air within the globes.

The instrument so constructed is exceedingly delicate, and will show a difference in the intensity of light sufficient to make one revolution per minute difference in the speed of the mill. As a photometer it is much more convenient than the mill, and its construction presents much less difficulty. By making the lower portion of the siphon-tube horizontal, and using glass indices after the manner of Rutherford's thermometer, the instrument might be made to record maxima and minima intensities of light, as well as be more delicate in other respects.

Measured with this instrument, the light necessary to give the mill 240 revolutions per minute does not exceed 24°, and is probably less than this, which shows that the theoretical difference of heat necessary to cause the heat-reactions is well within the difference as actually measured, leaving an ample margin for error in the methods of approximation used in the calculation.

In concluding the paper the author claims to have set at rest the only point respecting the explanation of the motion caused by heat which remained doubtful after he had discovered that, according to the kinetic theory, the communication of heat to a gas must cause a force reactionary on the surface, viz. whether this reaction was adequate in amount to cause the results seen to take place.

He adds a suggestion as to a new form of light-mill to have vanes inclined like the sails of a windmill, and not having one side white and the other black, like the light-mills at present constructed, arguing that the forces act perpendicularly to the surface, and in a direction independent of that from which the light comes; so that such a mill would turn like a windmill with the full and not merely the differential effect of the light. Such a mill, he concludes, would furnish another test as to whether or not the force is directly referable to radiation.

II. "On the Nature of the Force producing the Motion of a Body exposed to Rays of Heat and Light." By ARTHUR SCHUSTER, Ph.D., Demonstrator in the Physical Laboratory of Owens College. Communicated by B. STEWART, F.R.S., Professor of Natural Philosophy in Owens College, Manchester.

(Abstract.)

Mr. Crookes has lately drawn attention to the mechanical action of a source of light on delicately suspended bodies *in vacuo*; I have made a few experiments which will, I think, throw some light on the cause of the phenomenon, and assist us in the explanation of the manifold and striking experiments made by Mr. Crookes.

Whenever we observe a force tending to drive a body in a certain direction, we are sure to find a force equal in amount acting in the opposite direction on the body from which the force emanates. It was with the view of finding the seat of this reaction that I have made a few experiments.

If the force is directly due to radiation the reaction will be on the radiating body; if, on the other hand, it is due to any interior action, such as the one suggested by Prof. Reynolds, the reaction will be on the enclosure of the moving bodies. I have been able to test this by experiment, and I have found that the action and reaction is entirely between the light bodies suspended *in vacuo* and the exhausted vessel.

The instrument best fitted for an experimental investigation of this kind is the one which has been called "radiometer" by Mr. Crookes. These instruments have been made in great perfection by Dr. Geissler, of Bonn, under the name of "light-mills." Thanks to the courtesy of Prof. Reynolds, I have been enabled to work with such an instrument. The "light-mill" was suspended by means of two cocoon fibres, forming a bifilar suspension, from the top of a vessel which could be exhausted. A slight movement of the enclosure could be easily detected by means of a concave mirror attached to it. A beam of the oxyhydrogen lamp was concentrated on the light-mill, which then revolved about 200 times a minute.

The light was cut off at the beginning of the experiment by means of a screen, and the position of rest of the glass vessel was read off by means of the dot of light on the scale. The screen was then suddenly removed, and in every case a large deflection of the glass vessel was observed. The vessel was deflected in the opposite direction to that in which the mill turned. When the velocity of the mill had become constant, the vessel returned to its original position. On suddenly cutting off the light the vessel was again deflected, but in the opposite direction to that on starting the experiment. The vessel therefore now turned in the same direction in which the mill turned.

These experiments are easily explained on the assumption that the force acting on the vessel enclosing the light-mill is exactly equal and opposite to that acting on the mill itself. While the velocity of the mill in one direction is increasing, a force acts in the opposite direction on the vessel. When the velocity has become constant, the force which tends to drive the mill round is exactly counterbalanced by the resistance which opposes the motion of the mill. The two forces acting on the vessel will therefore counterbalance, and the vessel will return to its original position of rest. When the light is cut off, the resistance will stop the motion of the mill. The reaction of the resistance will act on the enclosure, and the enclosure will turn in the same direction as the mill.

By means of the reaction on the enclosure I have been able to calculate the strength of the force; and I have found that the pressure on a surface on which light of equal intensity to that used in my experiments falls, is equal to that produced by the weight of a film of water on a horizontal surface equal in thickness to the length of a wave of violet light.

III. "On the Number of Figures in the Period of each Reciprocal of a Prime from 53,000 to 60,000." By W. Shanks. Communicated by the Rev. G. Salmon, D.D., F.R.S., Regius Professor of Divinity in the University of Dublin. Received March 1st, 1876.

[In two former papers printed in the Proceedings (vol. xxii. pp. 200 and 384) the author gave similar tables from 1 to 30,000; and in a subsequent paper (Proceedings, vol. xxiii. p. 260), which was ordered to be preserved in the Archives, the table was extended to 40,000. A MS. copy of the addition appended to printed copies of his former paper and extended to 53,000 was presented by the author to the Society's library, and to this the present continuation from 53,000 to 60,000 will be attached.]

IV. "On a new Refractometer for measuring the Mean Refractive Index of Plates of Glass and Lenses by the employment of Newton's Rings." By G. W. Royston-Pigott, M.A., M.D. Cantab., F.R.S., F.R.A.S., F.C.P.S. Received March 19, 1876.

The instrument depends upon two principles :—

I. The distance through which an image is displaced by refraction through a plate.

II. The exquisite sensitiveness of contact-films forming the various orders of Newton's rings and the central black spot.

I. It is well known that when the index of refraction is 1·500 or $\frac{3}{2}$, an image is formed by a plate having parallel sides at a distance nearer to the eye of the observer equal to two thirds of the thickness of the plate. Indeed if t be the thickness and μ the refractive index, the displacement is generally

$$\frac{t}{\mu}.$$

If, therefore, an instrument could be devised which would with great accuracy measure the thickness of the refracting plate, and also at the same time the distance by which the image of points on its surface was displaced inwards by refraction, data could be obtained for determining the value of μ.

The instrument has assumed its present form after many constructions and reconstructions. I was led to consider this method of finding the refraction of glass by frequent accidents happening while using the fiftieth-of-an-inch objective with the microscope, which by pressure destroyed or cracked the thin glass covers generally applied to protect the objects or "slides." Now, so to speak, the observer always in such a case really examines the elevated image of the object, raised about two thirds of the thickness of this cover. By knowing, therefore, the refraction of the glass cover and its thickness, such accidents, so irreparable in many valuable objects, might be avoided. Means were sought to determine the index of refraction of such covers, frequently varying from the hundredth to the thousandth of an inch thick, an extra thickness sometimes being destructive to the most valuable objective.

Hitherto the method of finding the refractive index has been by the use of prisms made of the material in question, and employed in the form of a spectroscope.

As an example of the power of the instrument, some flint glass, nearly half an inch thick, marked B, gave on three trials

$$\begin{aligned} \mu &= 1{\cdot}6626 \\ & 1{\cdot}6626 \\ & 1{\cdot}6621 \\ \hline \text{Mean} &= 1{\cdot}6624 \end{aligned}$$

A thin glass cover about one hundredth of an inch thick gave

$$\mu=1{\cdot}5502.$$

The optical equation for a plate of glass,

$$v=u+\frac{t}{\mu}$$

(where u is the distance of the object and v the conjugate focus), points out that when the object is on the surface, or $u=0$,

$$v=\frac{t}{\mu};$$

and consequently

$$\mu=\frac{t}{v}.$$

Upon constructing an instrument roughly the index was readily found to two places of decimals in covering-glass, viz. $\mu=1{\cdot}55$.

The contrivance of an instrument to read to the 100,000th of an inch now seemed desirable. It was necessary not only to measure thickness, but the elevation of the image within the substance of the plate.

The well-known delicacy of evanishment of a point under a good microscope seemed to afford an exquisite test of distance.

At first the point of an advancing screw was made to touch the "plate," the screw moving in the axis of the microscope. The point was brought into focus, or rather its image. The refracting plate was now removed, the microscope remaining undisturbed. The screw was then advanced until its point again came into focus; the point now occupied the precise position just before occupied by its image. This distance was then read off and the thickness of the plate read by observing successively the distances traversed by the screw between the point of first contact and its rising to the very same position of a particle already observed on the upper surface.

II. At this point of the research it occurred to the writer to substitute a minute plano-convex lens, fixed to the end of the screw, and endeavour to produce contact-films, especially the black central spot of Newton's rings.

In order to render the colours of these rings gorgeous by reflected light, a thin piece of plate glass was fixed at an angle of 45° behind the observing objective, and a hole perforated in the tube or "body" to admit light from a lamp; the object-glass then condensed a strong light upon the film-forming surfaces, and the black central spot came out beautifully black and distinctly defined in the field of the microscope. This occurred whether air or other fluid intervened between the lens and the surface. After fixing several different lenses, I found a radius of curvature of about one quarter of an inch the most convenient for developing the rings suitably for the microscopic field of view.

For being apprised of the near approach of contact, still greater convenience was accorded by using a minute film of paraffin-oil, formed by repeatedly wiping the surface of the screw-lens. Contact was then heralded instantly between the two surfaces by a brilliant flash of colours. One thing appeared certain, the various colours could be produced in perpetually expanding and vanishing rings, always starting from the centre. I counted no less than thirty-two changes of colour in the central part, reckoning from the black spot of perfect contact (within the half-millionth of an inch) and the final evanescence of the last colour by slight movements of the screw.

For the purpose of illuminating the point of contact of the "screw-lens" with the plate under examination, I inserted a minute right-angled prism behind the lens. This giving totally reflected light, provided nothing adhered to the reflecting surface of the prism, afforded the means of making observations by ordinary daylight, and observing the rings of Newton, though very pale, by transmitted light.

Another great advantage of the prism-lens attached to the end of the steel measuring-screw, is the bright illumination of the contact surfaces, the contact of an opaque extremity of the screw being with difficulty ascertained.

The whole method of finding the refractive index of a thin plate of a given refractive material resolved itself, then, into the best instrumental means for advancing a fiducial visible and illuminated point truly and steadily through measurable intervals, and observing with a good microscope the precise position of evanishment in and out of focus, and determining the focal points under correct collimations.

After many trials the following form was adopted:—

A steel cylinder very accurately turned between *dead* centres (*i. e.* the centres being fixed and the object revolving between them), about 5 inches long and $\frac{3}{10}$ in diameter; upon this screw-threads (very nearly 101·3 per inch) were very patiently formed. The front part of the cylinder passes smoothly (at first air-tight like a piston) through a collar of brass, into which it had been very slowly and carefully ground (with the finest cutting-powder and oil); at about two inches of the other end was formed a screw as described, with a very exact apparatus lent to the writer by a celebrated optician.

It was found that in so delicate an operation as dealing with coloured films, touching any part of the instrument caused them to flash a new colour. It was necessary to obviate, then, all varying mechanical strain. Springs so common in micrometers to obviate "loss of time" were found to introduce, from their varying pressure, very variable errors: after a time I was compelled to abandon their use altogether.

The constant force of gravitation and dead unvarying weight was now introduced; and in order to compensate possible deviations in the true spiral form of individual threads (every one of which was carefully examined with a strong magnifying-power), a nut was formed, so as constantly to embrace (unlike ordinary micrometers of the usual form) precisely the same number of threads in every measurement, so that on the average the same number of threads probably represented nearly the same distance. In the case where a spring is more and more compressed and the number of threads embraced by the nut is constantly increasing (although some compensating action may arise), the screw and parts are certainly submitted to very varying and uncertain conditions. Another source of error arose,—*shake of rotation*. Having abandoned the usual form of micrometer construction (a revolving nut with a constant change in the number of threads embraced—a plan, one would think, fatal to all delicate accuracy), the next difficulty was to insure to the steel screw absolute advance and retreat without *rotatory* shake or motion. For this purpose *slides* were also abandoned. This action, the most important part of the instrument, should now be described.

A lever is affixed to the cylinder of steel and bent at right angles; it carries an adjustable weight. This weight slides upon a flat edge formed parallel to the axis of the steel screw by a most careful process, tested by a carefully prepared spirit-level for parallelism.

On lifting the weight slightly, the lever rotates the screw through a small angle; and this lever forms a constant test of the efficiency of the screw action of the greatest sensitiveness.

A further action put into motion by a fine screw gives to the advance of the film-forming surface, or prism-lens, a movement of the millionth of an inch.

Supposing that the recording-wheels have advanced several turns, the weight and lever also advance on the smooth edge already said to be formed parallel with the axis of the screw.

The constancy of the weight preserves the screw in one normal fiducial position, as regards its liability to rotate on its axis. An error of one hundredth of an inch in the sliding edge would produce an error of the reading of less amount than the hundred-thousandth of an inch [*]. But the lever advances so very slowly, as the wheels rotate the nut upon the screw, that this error appears to be almost destroyed.

An arrow-head shows upon the face of the differential wheels the number of turns taken by the nut. The instrument is self-recording, and reads to four places of decimals, from the hundredth of an inch to the hundred-thousandth. Two wheels, divided into 98 and 100 teeth respectively, run in gear *at will* with a long pinion of ten leaves, carrying a wheel showing the hundred-thousandths of an inch.

The prism end of the screw passes through the ground socket; and this socket carries a small stage accurately turned and ground, furnished with stops and a spring to confine the small plate of glass, if necessary, in one position. The axis of the screw and of the observing-microscope are carefully adjusted in one line, so as to have a common collimation.

---

[*] The path of the weight on the lever would be for a complete rotation about 20 inches; the proportion of $\frac{1}{100}$ to this is 2000, and the two thousandth part of a revolution is two thousandth of $\frac{1}{100} = \frac{1}{200000}$.

In very thin glass an objective of ¼-inch focal length has been found sufficient. For thick glass, nearly half an inch thick, Mr. Wray, of Highgate, made a beautiful half-inch with three lenses cemented together with balsam, so as to give the greatest possible penetration. The body of the microscope is about 6 inches long.

The whole instrument is placed at an angle of about forty degrees. Its accuracy depends on the weight of the toothed wheels always bearing with an equal pressure, without springs, on the back poppet of the jeweller's lathe employed to carry and work the apparatus.

It remains to say a few words on the method of using the instrument.

1. *By transmitted Light.*—The instrument is placed near a window in daylight, and the small condenser is then used to throw a light upon the minute prism, which is then reflected up the microscope. A minute drop of kerosine is placed on the prism-lens at the end of the micrometer-screw, and then wiped off. The lens is then withdrawn a little below the stage, and the plate of glass to be measured is placed upon it. The microscope is armed with a quarter-inch, a half inch, or inch objective, according to the thickness of the plate to be examined.

The microscope is then focused upon the under surface of the plate. The micrometer-wheels are set in motion. The prism-lens gradually rises into view. The instant of contact is observed by a sudden spreading out of the remains of the oil-drop. It may require several cleansings or wipings of the lens before the oil is sufficiently removed. The film expands and contracts with the slightest movement; with a little practice the eye detects the position of initial contact.

The instrument is then read.

Example.—Initial reading for a piece of "covering-glass" one hundredth of an inch thick,

$$I = 0{\cdot}0044.$$

The glass was removed and the prism-lens advanced until its surface just came into focus. The distance was then read.

$$\begin{aligned} D &= 0{\cdot}0086 \\ I &= 0{\cdot}0044 \text{ initial reading.} \\ \hline \Delta &= 0{\cdot}0042 \text{ the elevation of image.} \end{aligned}$$

Replacing the glass and again repeating the process the initial reading at the lower contact was now found not to be 0·0044, but

$$I_2 = 0{\cdot}0045 \text{ (an extra } \tfrac{1}{10000} \text{ inch).}$$

Viewing an exceedingly minute scratch on the upper surface by refocusing upon it, the reading for thickness was

$$\begin{array}{lll} & T=0\cdot0163 & \\ \text{Initial reading} & =0\cdot0045 & \\ \hline \text{Thickness} & =0\cdot0118 & \\ & \Delta=0\cdot0042 & \text{elevation of image.} \\ \hline & v=0\cdot0076 & \text{distance of image from upper surface.} \end{array}$$

Therefore $\mu=\frac{t}{v}=\frac{0\cdot0118}{0\cdot0076}=1\cdot55$ nearly.

I obtained from Mr. Browning several square pieces of flint glass of varying density and colour, and found by a series of measurements—

	Value of μ for mean rays.
A. Clear white flint	1·537
B. Yellow and heavy	1·6626
C. Yellowish and very heavy	1·723
D. Strong yellow, and the heaviest of them all..	1·7555

2. *By reflected Light.*—Far more interesting are the phenomena developed by reflected light, throwing the light laterally upon the inclined transparent plane within the microscope, the object-glass of which acts as its own condenser. The most beautiful colours are developed on contact, either with a film of air or kerosine.

The central spot of final contact is of a grey-black, surrounded with its well-known succession of Newtonian rings of great beauty and perfection, flashing through numerous changes of colour for each thickness of film varied by the micrometer-screw.

The instant of the formation of the black spot film (thickness 0·000005 inch) determines the place of contact, *i. e.* the fiducial point of zero, with a precision scarcely equalled by any other known method of linear measurement by optical means. It can be readily obtained with great accuracy. This important point (the zero) of the observations depends not upon a thin spider line or engraved line, but upon the formation of a bold black circular spot whose diameter is variable and dependent upon the curvature of the lens employed. Where great endurance is desired, a small plano-convex sapphire lens can be cemented to the prism at little expense.

The behaviour of minute microscopic kerosine oil-drops persistently adhering to the surface of the lens, in spite of repeated wipings, is worthy of notice.

On the near approach of the lens to the under surface of the glass under notice, the scattered drops suddenly coalesce, shooting out into a film of varying colour.

On one occasion a small oil-drop, one hundredth of an inch in diameter, appeared as a black annulus enclosing a bright thin ring of light, which enlarged on being touched by the prism-lens by the advance of the screw. It spontaneously then spread out and rapidly exhibited within its centre a sudden display of very minute but richly coloured Newtonian rings, formed in this case by interior reflected light, although transmitted light was then being employed.

It is not absolutely necessary that a plate of glass with precisely parallel sides be used. A wedge can be manipulated if a particular spot be chosen and the wedge be most carefully adjusted to the same position by means of the stop and ledge on the stage. Less difficult, however, is glass formed into a plano-convex lens of long focus, the plane side being placed downwards, and the same point, the summit if possible, being always selected for observation: better still if a slice be cut off so as to present a secure fixing of the lens in the same position.

A variety of substances formed into plates, wedges, or lenses, with little convexity, may thus be examined, as also fluids enclosed between parallel plates.

V. "Description of a Mammalian Ovum in an early condition of Development." By Edward Albert Schäfer, Assistant Professor of Physiology in University College, London. Communicated by Dr. Sharpey, F.R.S. Received March 8, 1876.

[Plate 10.]

The opportunities which present themselves for the acquisition of the ova of Mammalia during the early stages of development, and especially ova of the period during which the formation of the blastodermic layers is proceeding, are so rare that, although the subject has been under special investigation by more than one observer, all the stages of the process of formation have by no means as yet been described; and much remains to be discovered in connexion with this phase of development alone. It seems on this account desirable to publish observations bearing upon this question, although they are limited to two or three or even to a single ovum, since it is by collecting and comparing the results which have been arrived at by different observers that there will be the best chance of coming to a definite conclusion upon a subject which involves the knowledge of every progressive stage.

I have been induced by these considerations to furnish a short description of an early developing ovum (of the cat) which came into my hands now fully two years ago, but which I had continually deferred the account of in the hope of obtaining specimens a little more in advance with which to compare that which I already had. This expectation having, however, hitherto been disappointed, I think it better to communicate the description without further delay, as it may at least serve for comparison with the statements of other observers.

In a cat which had been just killed, I noticed on opening the abdomen five scarcely perceptible swellings in the cornua uteri; and perceiving a corresponding number of corpora lutea upon the ovaries, judged that each swelling must contain an ovum. Removing the uterus and placing it in a weak solution of bichromate of potash, I proceeded carefully to slit open the cornua under the fluid with fine scissors. As each one of the above-mentioned dilatations was reached, a minute, beautifully clear, vesicular body floated out into the surrounding liquid; there was no sign of any adhesion to the uterine wall.

The vesicles were as nearly as possible similar in size and appearance, and a description of any one of them will serve for all. Their shape was oval, the long diameter measuring about $\frac{1}{7}$ inch, the short about $\frac{1}{15}$ inch, and the outline being perfectly smooth and even. Under a low power of the microscope the vesicle was distinctly seen to be bounded by a primitive chorion or thinned-out zona pellucida. No trace of villi or projections of any sort could be detected on its surface. Besides this envelope the wall of the vesicle was composed of what appeared a simple layer of flattened polygonal cells, closely lining the zona. But under a somewhat higher power a stratum of more deeply lying cells could, in some parts at least, be detected by focusing; moreover a shadow at one place midway between the poles of the oval appeared to point to the possibility of the existence of a slight thickening at this part, although a well-defined *shaded* area was, in no sense of the word, visible.

I was led to imagine that the "shadow" in question, or rather the thickening to which it was probably due, would be caused by the first beginnings of a mesoblast at this situation. But nothing more could be made out in the fresh condition, and the little vesicles (at least two of them, for the others were of less value for the purpose of sections, owing to the blastoderm having shrunk away at various places from the zona, and presenting a crumpled distorted aspect) were accordingly hardened in the usual way in very dilute chromic acid, stained with logwood and with carmine respectively, imbedded by the gum-process*, with the object of filling the cavity and thus supporting the enclosing parts and preserving them in their natural positions; and finally sections were made across the long axis of the oval, and were mounted in glycerine and examined.

A glance at the sections is sufficient to show that the blastodermic vesicle is in the bilaminar condition. There exist within the zona pellucida, or primitive chorion, two distinct layers, the section of each forming a complete circle, the whole structure, therefore, included by the zona being formed of two separate vesicles one within the other (Plate 10. fig. 1). The outer of these is of course the epiblast, the inner doubtless representing the hypoblast: we may speak, then, of an epiblastic and a hypoblastic vesicle. In none of the sections was there any trace of an intermediate layer of cells or mesoblast. The epiblast closely lines the zona throughout; but the hypoblastic vesicle is considerably smaller, so that except at one part, where it comes into closer proximity than elsewhere with the epiblast, it is separated from the latter by a considerable interval, filled in the fresh condition by a clear fluid. This fluid would seem to be of a different nature from that which occupied the cavity of the hypoblastic vesicle, for the coagulum produced in it by the action of the hardening liquid has a much more granular appearance in the sections. Both epiblast and hypoblast throughout almost the whole extent are composed of a simple layer of flattened cells joined edge to edge. Those of the former are represented in fig. 2, as seen flat in a separated portion, those of the latter in fig. 3. Most of the epiblastic cells exhibit in a high degree a condition of the nucleus which is frequently met with in epithelial cells elsewhere—a tendency, namely, to become separated into a clear colourless part, and a highly refracting and usually somewhat irregular body, which readily becomes stained by the usual colouring reagents. This change is no doubt a post mortem effect, probably produced by the action of the reagents employed. The hypoblastic cells do not for the most part present this appearance; their nucleus remains large, round, and clear; and the cell-substance does not become stained as much as that of the epiblastic cells.

---

* A bad method for embryos; but I was at the time ignorant of Kleinenberg's excellent plan for effecting the same object. See Forster and Balfour, 'Elements of Embryology,' p. 249.

It was mentioned above that the epiblastic and hypoblastic vesicles come into closer proximity at one part of the circumference than elsewhere; even here, however, they do not come into actual contact. At this place they are no longer formed, as elsewhere, of a single layer of cells, but their component elements, besides being rounder in shape and smaller, are two or three deep, although not arranged in as many definite strata. Both layers are in consequence somewhat thickened just here, the thickening (which is most marked in the epiblastic vesicle) extending over an area of about $\frac{1}{60}$ inch in diameter; not sharply defined, however, but gradually shading off into the thin part. Both epiblast and hypoblast are, it may be repeated, perfectly well defined and distinct from one another here as elsewhere; and there are no cells to be seen which do not clearly belong to one or the other. Moreover they are not only separated by a small but obvious amount of the granular material (coagulated fluid) previously mentioned, but there is in addition an exquisitely fine pellicle, which in the sections appears as a mere line passing over and forming a definite boundary to the upper (outer) surface of the hypoblast at the thickened area. This membranous pellicle, for which I would venture to propose the name of *membrana limitans hypoblastica*, is, as made out in teased preparations, perfectly homogeneous, and continues so throughout its extent. It becomes stained slightly by carmine, but apparently not at all by logwood, and is probably to be looked upon as a cuticular formation produced by the hypoblastic cells. Whether the delicate pellicle may extend around the whole hypoblast in the natural condition I am unable to say; in the sections, at any rate, it appears to terminate towards the periphery of the thickened area, and to have become curled somewhat away from the hypoblast.

I am not aware that a similar structure has yet been noticed in the early blastoderm of any animal; but its importance in this case in bounding the hypoblast is evident. Indeed, if it should be found that the membrane in question is of general occurrence in the mammalian germ, and that the first appearance of the mesoblastic cells occurs external to it, as from its proximity to the hypoblast there is little reason to doubt, the fact of the existence of such a film between the commencing mesoblast and hypoblast is strongly in favour of the view which derives the former from cells of the epiblast as against that which would assign to it a hypoblastic origin.

[Since writing the above I have been enabled, through the medium of the Royal Society Library, to see a recent number of the new 'Zeitschrift für Anatomie und Entwickelungsgeschichte,' which contains a paper by Hensen on the early stages of development of the rabbit's ovum. In sections of one blastoderm, of which he gives figures, there is a delicate line at the *anterior part* of the germinal area lying midway between the epiblast and hypoblast and marked *m.pr.* This is referred to in the Description of the Plate as "vielleicht die erste Anlage der *membrana prima.*" Unfortunately, although all the figures appear to be given, the text of the paper is incomplete (the completion is promised in the next Number); and the full description of this blastoderm and the account of the so-called "membrana prima" are for the present altogether wanting. But from Hensen's figure I have very little doubt that his "membrana prima" is a structure analogous with that described by me in the cat's ovum as "membrana limitans hypoblastica," although the position and relations of the membrane, especially with regard to the hypoblast, appear somewhat differently in our respective drawings. I think the name "membrana prima" is, however, by no means well chosen for the structure in question; for, leaving out of consideration the primitive chorion, do not the early embryonic cells (the products of segmentation) themselves compose the *first membrane*? as the very name which has been assigned to them collectively since the time of Pander itself directly implies.]

DESCRIPTION OF PLATE 10.

Fig. 1. Diagram of a vertical section across the middle of the developing ovum. Magnified.

z.p. Section of the zona pellucida or primitive chorion.
e.v. Vesicle formed by the epiblast.
h.v. Vesicle formed by hypoblast much smaller than the former.
g. Opposite the thickened portion of both layers (germinal area).

Schafer Proc. Roy. Soc. Vol. 24. Pl. 10

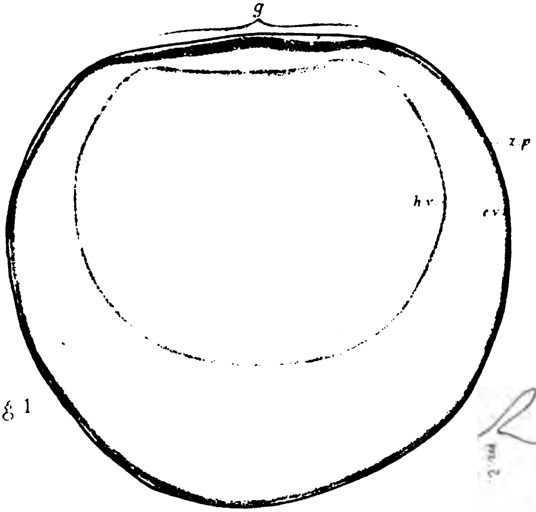


Fig. 1

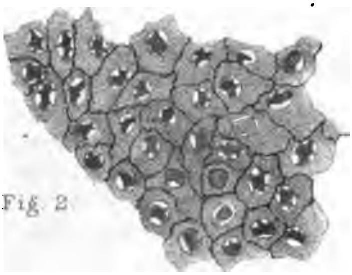


Fig. 2

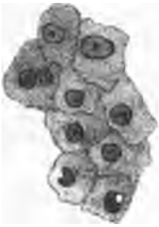


Fig. 3

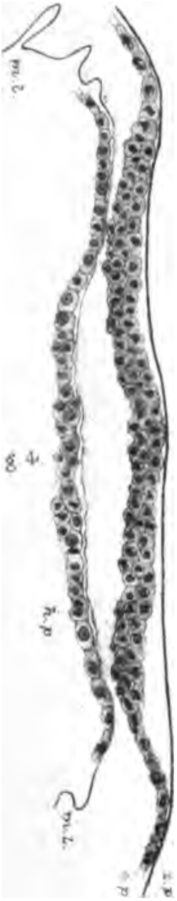


Fig. 4

W. H. Wesley lith. Schafer del.^t [illegible]

Fig. 2. Piece of the epiblast; the cells and nuclei stained with carmine. Magnified about 370 diameters.

Fig. 3. Piece of the hypoblast; similarly prepared. Magnified 370 diameters.

Fig. 4. Section across the germinal area of the developing ovum, stained with logwood. Magnified 200 diameters.

z.p. zona pellucida.
e.p. epiblast.
h.p. hypoblast.
m.l. Membrana limitans hypoblastica.

VI. "Preliminary Report to the Hydrographer of the Admiralty on some of the Results of the Cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso." By Prof. Wyville Thomson, F.R.S., Director of the Civilian Staff on board. Received February 26, 1876.

[This Report will appear in a subsequent Number of Proceedings.]

March 30, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "An Experiment on Electro-Magnetic Rotation." By W. Spottiswoode, M.A., Treas. and V.P.R.S. Received February 24, 1876.

The phenomena of the rotation of movable conductors, carrying currents, about lines of magnetic force are well known. One form of experiment, commonly called the rotating spark, presents, beside the actual rotation, some peculiar features which do not appear to have been noticed in detail. The instrumental arrangements consist of a partially exhausted chamber with a platinum point for one terminal, a ring for the other, and the intervening air or other gas for the movable conductor. The chamber is made in the form of a double cylinder, so that a magnet inserted through the ring may reach nearly to the point. The discharge then passes between the point and the ring, and revolves about the magnet according to Ampère's law.

But beside the rotation, and even when, through weakening of the magnet, rotation does not actually take place, the spark, when carefully observed, is seen to assume a spiral form; and the spiral is right-handed or left-handed according to both the direction of the current and the magnetic polarity. This effect is particularly noticeable if the magnetic pole be inserted only a short distance beyond the ring. The discharge is then seen to spread itself out sheetwise on the ring in the direction in which rotation would take place. The edge of the sheet is in the form of a helix.

The object of the following observations is to bring out the character of this phenomenon by making it a principal instead of a secondary feature of the experiment.

The arrangement here described consisted in using the poles of an electromagnet as the terminals of a discharge from an induction-coil, and in observing the effect on the form of the discharge caused by exciting the electromagnet. For this purpose the movable poles were insulated from the main body of the magnet by interposing a sheet of ebonite thick enough to prevent the passage of the discharge, but not thicker, in order as little as possible to diminish the strength of the magnetic poles. The discharge was then effected either in the open air or in a closed chamber. The latter was constructed of a short cylinder of glass, say 3 inches in length and 2 in diameter, having conical ends pointed inwards, so as to receive the poles of the magnet. The chamber was also furnished with a pipe and stopcock for the purposes of exhaustion.

The discharge from an induction-coil taken in air or other gas at atmospheric pressure consists, as is well known, primarily of the spark proper or bright line, irregular in form and instantaneous in duration. But beside this, when the primary wire is thick and the battery-current strong, the spark is enveloped in a bright cloud, or rather flame, which is capable of being thrown on one side, although not entirely detached from the spark, by a current of air. This, when examined in a revolving mirror, is found to be subsequent in time to the spark proper, and may be considered to be due to the gas in the neighbourhood of the spark becoming sufficiently heated to conduct part of the discharge, and to the consequent combustion of any extraneous matter floating in the medium. Such a view is supported by the fact that the colour of this flame depends partly upon the nature of the gas in which the discharge takes place, and partly upon that of any volatilizable matter which may be introduced near the poles.

The exciting of the magnet produces upon the spark proper no appreciable effect; but as soon as the flame is submitted to its action it is spread out into a sheet, which arranges itself in a helicoid right-handed or left-handed according to the direction of the current and of the magnetic polarity in obedience to Ampère's law.

Effects substantially the same are produced whether the discharge be taken in gas at atmospheric or at a less pressure. But in the former case the helix has a lower, in the latter a steeper gradient; that is to say, in the former case it presents a greater, in the latter a less number of turns for a given interval between the poles.

But for producing the best effects, both of the rotating spark and also of the spirals, there is a limit beyond which the exhaustion should not be carried. At a pressure low enough to produce stratification, or even short of it, the whole chamber is filled with the discharge, and all traces of rotation and of spirals are obliterated. The stage best suited to the purpose is that in which the discharge has thickened in diameter, and where the spark proper has been replaced by a suffused light of the thickness, say, of a quill. If the negative terminal be a surface (say the naked surface of the soft iron pole of the electromagnet) instead of a point, the sheet does not become contracted at the negative end, but remains spread out and cuts the iron pole in a line radiating from the point.

Various gases were tried—atmospheric air, carbonic acid, ether, chloroform, coal-gas, hydrogen. Of these the first two succeeded best. With air the illumination of the flame-sheet was rather greater; but with carbonic acid greater steadiness of position was obtained. With both ether and chloroform occasional flashes, brilliantly illuminated, were seen; but some chemical action appeared to take place militating against the steady development of the flame-sheet. With coal-gas there was an inconvenient deposit of carbon upon the sides of the chamber. With hydrogen the cloud was not sufficiently developed.

The success which attended the experiment with air may possibly be partly due, as suggested above, to the combustion of the extraneous matter floating therein; and in fact the brilliancy and extent of the sheet may be increased by attaching a piece of metallic sodium to the negative terminal, or by causing a stream of any of the chlorides in powder, *e. g.* of strontium, lithium, &c., to flow across the field of action.

When a piece of sodium (or better still of soda) is attached to one of the terminals, two effects may be noticed. When that terminal is negative the whole of the flame is bright yellow, showing that the sodium is not only detached but even carried across the field and deposited on the positive terminal. When, however, the terminal to which the sodium is attached is positive, it is found that the flame, when observed through a red glass, appears yellow to a certain distance from that terminal, but red beyond, and also that the pitch of the helix is less near the positive than near the negative terminal. These effects may be attributed to the presence of metallic vapour evolved by the heat at the positive terminal, but not carried across the field as when the terminal in question is negative.

The following explanation of the phenomenon is due to Prof. Stokes, from whose correspondence it is substantially taken. The mathematical solution, although only roughly approximate, is perhaps still quite sufficient to give the general character of the experimental results.

The magnetic field will be supposed uniform, and the lines of force parallel straight lines from pole to pole. The path of the current when undisturbed is also a straight line from pole to pole. In such a condition of things, every thing being symmetrical, no rotation would take place.

But if through any local circumstance, as in the experiment in air, or through heating of the chamber as in the exhausted tube, or otherwise, the path of the current be distorted and displaced, then each element will be subject to the action of two forces. To estimate these, let ds be an element of the path, with rectangular components dx, dy, dz, C the strength of the current, and R the magnetic force with components X, Y, Z, which in the first instance will be treated generally. Then one force will be that tending to impel the current in the direction of the axes respectively, and may be expressed by

$$C(Ydz-Zdy):ds,\quad C(Zdx-Xdz):ds,\quad C(Xdy-Ydx):ds.$$

Besides this, there will be the tendency of the current to follow the shortest path so as to diminish the resistance. Representing this as a tension τ, the components at one end of ds will be

$$-\tau dx:ds,\ -\tau dy:ds,\ -\tau dz:ds,$$

and those at the other

$$(\tau dx:ds)+d(\tau dx:ds)\ \ldots,$$

the algebraical sums of which are

$$d(\tau dx:ds),\ d(\tau dy:ds),\ d(\tau dz:ds),$$

and the equations of equilibrium then become

$$C(Ydz-Zdy)+d(\tau dx:ds)=0,\quad \ldots\ldots \quad (1)$$
$$C(Zdx-Xdz)+d(\tau dy:ds)=0,\quad \ldots\ldots \quad (2)$$
$$C(Xdy-Ydx)+d(\tau dz:ds)=0;\quad \ldots\ldots \quad (3)$$

taking s as the independent variable and multiplying by $dx:ds$, $dy:ds$, $dz:ds$ respectively, and adding, we obtain $d\tau=0$, or $\tau=$constant. Again, multiplying by X, Y, Z and adding we obtain

$$Xd^2x:ds^2+Yd^2y:ds^2+Zd^2z:ds^2=0,\quad \ldots \quad (4)$$

which expresses that the absolute normal (or normal in the osculating plane) is perpendicular to the resultant magnetic force.

In the case of a uniform tint, X, Y, Z will be constant. Integrating (4) and putting i for the angle between the tangent and the lines of magnetic force, we find

$$Xdx+Ydy+Zdz=Rds\cos i,$$

so that the tangent line is inclined at a constant angle to the line joining the poles.

Again, the following combinations, (2) $dz-(3)dy=0$, (3) $dx-(1)dz=0$, (1) $dy-(2)dx=0$ give

$$Cdx(Xdx+\,.\,.)-CXds^2+\tau\left(\frac{dz}{ds}\frac{d^2y}{ds^2}-\frac{dy}{ds}\frac{d^2z}{ds^2}\right)ds^2=0,\ \&c.,$$

or

$$C(R\cos i\,dx-Xds)+\tau\left(\frac{dz}{ds}\frac{d^2y}{ds^2}-\frac{dy}{ds}\frac{d^2z}{ds^2}\right)ds=0,\ \&c.$$

Transposing, squaring, and adding, and putting ρ for the radius of curvature, we obtain

$$C^2R^2\sin^2 i = r^2 : \rho^2, \text{ or } \rho = r : CR\sin i,$$

which is constant. The curve is therefore a helix. Also the radius of curvature of the projection of the curve on a plane perpendicular to the axis will be $\rho\sin^2 i$, viz. $= r\sin i : CR$.

"The value of r depends doubtless on the nature and pressure of the gas, and perhaps also on the current; but it must be the same for equal values of C of opposite signs. Hence the handedness of the helix will be reversed by reversing either the current or the magnetic polarity. If the left-hand magnetic pole be north (*i. e.* austral, or north-pointing), and the left-hand terminal positive, the helix will be right-handed."

The general nature of the phenomenon may therefore now be described as follows:—"First, we have the bright spark of no sensible duration which strikes nearly in a straight line between the terminals. This opens a path for a continuous discharge, which being nearly in a condition of equilibrium, though an unstable one, remains a short time without much change of place. Then it moves rapidly to its position of equilibrium, the surface which is its locus forming the sheet. Then it remains in its position of equilibrium during the greater part of the discharge, approaching the axis again as the discharge falls, so that its equilibrium position is not so far from the axis. Thus we see two bright curves corresponding to the two positions of approximate rest united by a less bright sheet, the first curve being nearly a straight line, and the second nearly a helix traced on a cylinder of which the former line is a generating line.

"It was noticed that the sheet projected a little beyond the helix. This may be explained by considering that at first the discharge is more powerful than can be maintained, so that the curve reaches a little beyond the distance that can be maintained."

The appearance of the discharge when viewed in a revolving mirror (except the projection beyond the sheet, the illumination of which was too feeble to be observed) confirmed the above remarks.

II. "The Residual Charge of the Leyden Jar." By J. Hopkinson, M.A., D.Sc. Communicated by Prof. Sir William Thomson, F.R.S.

(Abstract.)

1. If it be assumed that a dielectric under electric induction has every element of volume of its substance in an electropolar state, and also that dielectrics have a property analogous to coercive force in magnetism whereby time is requisite for the development or decay of this electropolar state, an explanation of the residual charge of the Leyden jar

easily follows. Adding the hypothesis, which at first sight appears most probable to connect the induction and polarization with the time by two differential equations, it follows that the potential E of a Leyden jar when insulated may be expressed in the form $E=(A+B\epsilon^{-\mu t})\epsilon^{-\lambda t}$, where λ and μ are constants for the material, and A and B depend on the previous states of the dielectric.

2. Observations made with the quadrant electrometer, the condenser being a Florence flask containing sulphuric acid, show that E cannot be so expressed. Glass is a mixture of different silicates, and it may be supposed that each substance is capable of independently being electropolar; there will thus be E and more than one polarity to be connected with the time by more than two differential equations. Making a similar obvious hypothesis regarding these relations, E must be expressed in the form $\sum_{0}^{r} A_r \epsilon^{-\lambda_r t}$. If this be so, it would probably be possible to charge a Leyden jar in such a way that the sign of the return charge after discharge and insulation should change once or more.

3. This anticipation was verified by charging the flask alternately positively and negatively for successively decreasing periods. The author learned after making this verification that Sir William Thomson had tried similar experiments before, but had never formally published them.

4. The analogy between coercive force in magnetism and the electrocoercive force suggested that, as mechanical agitation shakes out the magnetism from a magnet, so it might shake down the electropolar state of a dielectric and unmask residual charge more rapidly than is the case in quiescence. This was found to be the case; a residual charge manifests itself in the flask more rapidly when the flask is tapped than when it is quiet. It was also found that that portion of the return charge which comes out last is more accelerated by vibration than that which comes out first, and that, after tapping, the flask was less susceptible to the effect of tapping than it was before it was touched.

5. Experiment shows that, after a return charge has attained a maximum and is decreasing by conduction through the glass, the loss per cent. per unit of time does not continuously increase from zero at the point of maximum potential but may presently decrease.

6. Sir William Thomson explained specific inductive capacity by supposing every part of the dielectric to be electropolar under induction; by introducing time into that explanation, it is made to cover both specific inductive capacity and that on which residual charge depends as respectively rapid and slow cases of similar phenomena.

III. "On the Placentation of the Lemurs." By WM. TURNER, M.B. (Lond.), Professor of Anatomy, University of Edinburgh. Communicated by Prof. HUXLEY, Sec. R.S. Received February 21, 1876.

(Abstract.)

In the Introduction to this Memoir a description was given of the observations made by M. Alphonse Milne-Edwards on the gravid uteri of several genera of Lemurs. The author then proceeded to describe the gravid uteri of six Lemurs which he had received from Dr. Andrew Davidson, of Antananarivo, Madagascar, viz. *Propithecus diadema*, *Lemur rufipes*, and *Indris brevicaudatus*. He then summarized the conclusions he had arrived at in the course of his dissections, and showed that the placenta in these animals was diffused and presumably therefore non-deciduate. The paper concluded with a discussion of the bearing of these observations on the classification of the Lemurs, and on the theory propounded by Haeckel of the descent of the deciduate mammals from a primæval root-form of Prosimiæ.

IV. "On the Movement of the Glass Case of a Radiometer." By WILLIAM CROOKES, F.R.S. &c. Received March 30, 1876.

During the discussion which followed the reading of Prof. Reynolds's and Dr. Schuster's papers at the last meeting of the Royal Society I mentioned an experiment bearing on the observations of Dr. Schuster. I have since tried this in a modified form; and as the results are very decided and appear calculated to throw light on many disputed points in the theory of these obscure actions, I venture to bring a description of the experiment, and to show the apparatus at work, before the Society.

I made use of a radiometer described in a paper communicated to the Society in January last. I quote the description from paragraph 184. "A large radiometer in a 4-inch bulb was made with ten arms, eight of them being of brass and the other two being a long watch-spring magnet. The disks were of pith, blackened on one side. The power of the earth on the magnet is too great to allow the arms to be set in rotation unless a candle is brought near; but once started it will continue to revolve with the light some distance off."

This radiometer was floated in a vessel of water; and four candles were placed round it so as to set the arms in rotation. A mark was put on the glass envelope so as to enable a slight movement of rotation to be seen. The envelope turned very slowly a few degrees in one direction, then stopped and turned a few degrees the opposite way; finally it took up a uniform but excessively slow movement in the direction of the arms, but so slow that more than an hour would be occupied in one revolution.

A powerful magnet was now brought near the moving arms. They immediately stopped, and at the same time the glass envelope commenced to revolve in the opposite direction to that in which the arms had been revolving. The movement kept up as long as the candles were burning, and the speed was one revolution in two minutes.

The magnet was removed, the arms obeyed the force of radiation from the candles and revolved rapidly, whilst the glass envelope quickly came to rest and then rotated very slowly the same way as the arms went.

The candles were blown out; and as soon as the whole instrument had come to rest a bar-magnet was moved alternately from one side to the other of the radiometer, so as to cause the vanes to rotate as if they had been under the influence of a candle. The glass envelope moved with some rapidity (about one revolution in three minutes) in the direction the arms were moving. On reversing the direction of movement of the arms the glass envelope changed direction also.

These experiments show that the internal friction, either of the steel point on the glass socket, of the vanes against the residual air, or of both these causes combined, is considerable. Moving the vanes round by the exterior magnet carries the whole envelope round in opposition to the friction of the water against the glass.

As there is much discussion at present respecting the cause of these movements, and as some misunderstanding seems to prevail as to my own views on the theory of the repulsion resulting from radiation, I wish to take this opportunity of removing the impression that I hold opinions which are in antagonism to some strongly urged explanations of these actions. I have on five or six occasions specially stated that I wish to keep free from theories. During my four years' work on this subject I have accumulated a large fund of experimental observations, and these often enable me to see difficulties which could not be expected to occur to an investigator who has had but a limited experience with the working of one or two instruments.

Presents received, March 2, 1876.

Transactions.

Birmingham:—Institution of Mechanical Engineers. Proceedings, 1875. No. 2 (April). 8vo. The Institution.

Edinburgh:—Royal Scottish Society of Arts. Transactions. Vol. VIII. Part 5; Vol. IX. Part 1, 2. 8vo. 1873–74. The Society.

London:—East-India Association. Journal. Vol. IX. No. 1–3. 8vo. 1875–76. The Association.

Linnean Society. Journal. Zoology. Vol. XII. No. 60–62. 8vo. 1876. The Society.

Transactions (*continued*).

Royal Asiatic Society. Journal. New Series. Vol. VIII. Part 1. 8vo. 1875. The Society.

Royal Institute of British Architects. Sessional Papers. 1874–75. No. 12, 13; 1875–76. No. 1–6. 4to. The Institute.

Manchester:—Scientific and Mechanical Society. Publications V., VI. (Hildebrandt on Tramways and Niemann's Iron System). 8vo. 1875. The Society.

Reports, Observations, &c.

London:—Meteorological Office. Minutes of the Proceedings of the Meteorological Committee, 1875. folio. 1876. Hourly Readings. July 1875. folio. The Office.

Paris:—l'Observatoire. Atlas Météorologique. Années 1872, 1873, et 1874. 4to. *Paris* 1875. The Observatory.

St. Petersburg:—Kaiserliche Akademie der Wissenschaften. Repertorium für Meteorologie, redigirt von Heinrich Wild. Band IV. Heft 2. 4to. 1875. The Academy.

Turin:—Regio Osservatorio della Regia Università. Bollettino Meteorologico ed Astronomico. Anno 8, 9. 4to. *Torino* 1875. Effemeridi del Sole, della Luna e dei principali pianeti, 1874, 1875. 8vo. L'Aneroide a Vite Micrometrica sperimentato colle differenze di livello delle Strada Ferrata delli Alpi, da Alessandro Dorna. 8vo. 1874. Circostanze del Passaggio di Venere del 1874 calcolate per la linea Madras-Calcutta, da Alessandro Dorna. 4to. 1874. The Observatory.

Dewalque (G.) Rapports sur l'étage dévonien des psammites du Condroz. 8vo. *Bruxelles* 1875. Rapport sur le système houiller du bassin de Liége. 8vo. 1875. The Author.

Marignac (C.) Sur les Chaleurs spécifiques des Solutions Salines. 8vo. *Genève* 1876. The Author.

Raimondi (Antonio) El Peru. Tomo I. Parte Preliminar. roy. 8vo. *Lima* 1874. The Peruvian Government.

Rütimeyer (L.) Ueber Pliocen und Eisperiode auf beiden Seiten der Alpen. 4to. *Basel* 1876. The Author.

Secchi (Angelo), For. Mem. R.S. Sulle Protuberanze Solari e loro relazione colle Macchie. Nona, (decima e undecima) Comunicazione. 4to. *Roma* 1873–74. Di Alcuni fatti relativi all' origine della Grandine Nota. 4to. 1876. The Author.

Vincent (Charles W.) The Year-Book of Facts in Science and the Arts for 1875. 8vo. *London* 1876. The Editor.

March 9, 1876.

Transactions.

Bordeaux:—Société des Sciences Physiques et Naturelles. Mémoires. 2^e série. Tome I. Cahier 2. 8vo. 1876. Extrait des Procès-Verbaux des Séances. 1874–75. 8vo. The Society.

Buffalo Society of Natural Sciences. Bulletin. Vol. III. No. 1. 8vo. 1875. The Society.

Calcutta:—Asiatic Society of Bengal. Journal, 1875. Part 1. No. 2. 8vo. 1875. Proceedings, 1875. No. 7, 8. 8vo. 1875. The Society.

Dresden:—Verein für Erdkunde. Dritter Jahresbericht. 8vo. 1866. The Institution.

Dublin:—Royal Geological Society of Ireland. Journal. Vol. XIV. Part 2. 8vo. 1875. The Society.

London:—London Institution. Journal. Vol. IV. No. 25, 26; and Lecture Supplement. 8vo. 1874–75. The Institution.

Paris:—Société Géologique de France. Bulletin. 3^e Série. Tome II. ff. 44–46. 8vo. 1874. The Society.

Société de Géographie. Bulletin. Déc. 1867, Sept. 1874, Fév., Nov., Déc. 1875, Jan. 1876. 8vo. The Society.

Reports &c.

Albany:—Annual Report of the Canal Commissioners of the State of New York. 8vo. 1875. The Commissioners.

Cambridge, U. S.:—Museum of Comparative Zoology at Harvard College. Annual Report of the Trustees for 1874. 8vo. 1875. Illustrated Catalogue. No. 8. Zoological Results of the Hassler Expedition. II. Ophiuridæ and Astrophytidæ. 4to. 1875. The Museum.

London:—Reports of the Medical Officer of the Privy Council and Local Government Board. New Series. No. 4, 5, 6. 8vo. 1875. J. Simon, F.R.S.

Vienna:—K. k. Sternwarte. Annalen. Dritter Folge. Band XXIV. Jahrgang 1874. 8vo. *Wien* 1875. The Observatory.

Washington:—Smithsonian Institution. Annual Report of the Board of Regents for the year 1874. 8vo. 1875. The Institution.

Kirkman (T. P.), F.R.S. Philosophy without Assumptions. 8vo. *London* 1876. The Author.

Mandoz (Tommaso) Ricerche Fisiche intorno alla Luce ed ai Colori proprii dei Corpi. 8vo. *Napoli* 1875. The Author.

Rumford (Count) Complete Works. Vol. IV. 8vo. *Boston* [*U. S.*] 1875. The American Academy.

Ruolz (de) Question des Houilles. Mission de M. de Ruolz en France et en Angleterre. 3 vols. roy. 8vo. *Paris* 1872–75.

March 16, 1876.

Transactions.

Bordeaux :—Société de Géographie Commerciale. Bulletin. No. 1. Année 1874–75. 8vo. 1876. The Society.

Edinburgh :—Royal Society. Transactions. Vol. XXVII. Part 3. 4to. 1875. Proceedings. Session 1874–75. 8vo. The Society.

Erlangen :—Physikalisch-medicinische Societät. Sitzungsberichte. Heft 7. 8vo. 1875. The Society.

Göttingen :—Königliche Gesellschaft der Wissenschaften. Abhandlungen. Band XX. 4to. 1875. Nachrichten. 1875. 12mo. The Society.

Toulouse :—Académie des Sciences. Mémoires. Septième Série. Tome VII. 8vo. 1875. The Academy.

Reports &c.

Albany :—New-York State Library. Fifty-sixth and Fifty-seventh Annual Reports. 8vo. 1874–75. The Trustees.

Regents of the University of the State of New York. Eighty-sixth and Eighty-seventh Annual Reports. 8vo. 1873–74. Annual Reports on the New-York State Museum of Natural History. 23, 24, 25, 26. 8vo. 1872–74. The Regents.

London :—Rivers Pollution Commission (1868). Reports of the Commissioners. 1 to 6, in 2 vols. folio. *London* 1870–74. Dr. Frankland, F.R.S.

Paris :—École des Mines. Annales des Mines. Septième Série. 2, 3, 4, 5 livraisons de 1875. 8vo. The École.

Washington :—Annual Report of the Supervising Surgeon of the Marine-Hospital Service of the United States for the fiscal year 1874. 8vo. Dr. Woodworth.

The Cholera Epidemic of 1873 in the United States. 8vo. 1875. Dr. Woodworth.

Topographical Atlas projected to illustrate Geographical Explorations and Surveys West of the 100th Meridian of Longitude, by George M. Wheeler. 4to. Lieut. Wheeler.

United-States Geological Survey of the Territories. Report. Vol. II. Vertebrata of the Cretaceous Formations of the West, by E. D. Cope. 4to. 1875. F. V. Hayden, U. S. Geologist.

Cargill (David) Preventing and extinguishing Fire on board Ships. Three methods of applying Carbonic-acid Gas in extinguishing Fire. 8vo. *Dundee* 1876. The Author.

Morren (E.) Correspondance Botanique. Liste des Jardins, des Chaires, et des Musées Botaniques du Monde. 8vo. *Liége* 1875. The Author.

Ellero (Pietro) Scritti Politici. 8vo. *Bologna* 1876. The Author.

March 23, 1876.

Transactions.

Emden:—Naturforschende Gesellschaft. Sechzigster Jahresbericht, 1874. 8vo. *Emden* 1875. Kleine Schriften XVII. (Ergebnisse der Witterungs-Beobachtungen von 1864 bis 1873, von Dr. M. A. F. Prestel). 4to. *Hannover* 1875. The Society.

Graz:—Naturwissenschaftlicher Verein. Mittheilungen. Jahrgang 1875. 8vo. 1875. The Institution.

London:—Mathematical Society. Proceedings. No. 79–84. 8vo. 1875. The Society.

Modena:—Società dei Naturalisti. Anuario. Serie II. Anno 9. fasc. 3, 4. 8vo. 1875. Catalogo della Biblioteca. Puntata prima. 1875. 8vo. The Society.

Stockholm:—Kongl. Svenska Vetenskaps Akademien. Handlingar. Ny Följd. Bandet IX. Delen 2; Bandet X., XII. 4to. 1870–73. Bihang. Bandet I., II. 8vo. 1872–75. Öfversigt af ... Förhandlingar. Årgången 28, 29, 30, 31. 8vo. 1871–75. Lefnadsteckningar. Band I. Häfte 3. 8vo. 1873. Minnesteckning öfver Hans Järta af Louis de Geer. 8vo. 1874. Minnesteckning öfver Jacob August von Hartmansdorff, af Henning Hamilton. 8vo. 1872. Meteorologiska Iakttagelser i Sverige. Bandet XII., XIII., XIV. 4to. 1870–72. Icones selectæ Hymenomycetum nondum delineatorum. 7–10. folio. The Society.

Trieste:—Società Adriatica di Scienze Naturali. Bollettino. Nrs. 6, 7. 8vo. 1875. The Society.

Vienna:—K. k. Geologische Reichsanstalt. Jahrbuch. Band XXV. No. 4. roy. 8vo. *Wien* 1875. Verhandlungen. 1875. No. 14–18. roy. 8vo. The Institution.

Oesterreichischer Ingenieur- und Architekten-Verein. Bericht des Hydrotechnischen Comité's über die Wasserabnahme in den Quellen, Flüssen, und Strömen. 8vo. *Wien* 1875. The Institution.

Bessels (E.) The Tides at Polaris Bay, with Chart showing the approximate Cotidal Lines of the North Atlantic and North Pacific Oceans and the Arctic Seas. folio. *Washington* 1876.
The Smithsonian Institution.

Crozier (C^{te} de) L'Art Khmer. Étude historique sur les Monuments de l'ancien Cambodge. 8vo. *Paris* 1875. The Author.

Jervis (W. P.) The Anthracite Coal of Demonte, near Cuneo, in the Italian Alps. 8vo. *London* 1875. Sul Giacimento di Carbon fossile antracitico di Demonte. 8vo. *Milano* 1875. The Author.

Lebour (G. A.) On the Limits of the Yoredale Series in the North of England. 8vo. *London* 1875. The Author.

Matthews (T.) A mode of Trisecting a Plane Rectilineal Angle by the use of Circles and Straight Lines only. 8vo. *Horsham* 1875.
The Author.

Millar (W. J.) On the Strength and Fracture of Cast Iron. 8vo. *Glasgow* 1875. The Author.

Thurston (R. H.) On the Necessity of a Mechanical Laboratory, its province and its methods. 8vo. *Philadelphia* 1875. The Author.

March 30, 1876.

Transactions.

Innsbruck:—Naturwissenschaftlich Medizinischer-Verein. Berichte. VI. Jahrgang. 1875. Heft 1. 8vo. 1876. The Society.

Lausanne:—Société Vaudoise des Sciences Naturelles. Bulletin. 2e Série. Vol. XIV. No. 75. 8vo. 1876. The Society.

Paris:—Société Française de Physique. Séances. Mai–Décembre 1875. 8vo. The Society.

Pisa:—Società Toscana di Scienze Naturali residente in Pisa. Atti. Vol. II. fasc. 1. 8vo. 1876. The Society.

Vienna:—Kaiserliche Akademie der Wissenschaften. Denkschriften. Math.-nat. Classe. Band XXXIV. 4to. *Wien* 1875. Sitzungsberichte. Math.-nat. Classe. Band LXX. Heft 3–5. Abth. 1, 2, 3; Band LXXI. Heft 1–5. Abth. 1, 2; Heft 1, 2. Abth. 3. 8vo. 1875. Philos.-hist. Classe. Band LXXVIII. Heft 2, 3; Band LXXIX. Heft 1–3; Band LXXX. Heft 1–3. 8vo. 1874–75. Almanach. Jahrgang 25. 1875. 8vo. The Academy.

Reports, Observations &c.

Cambridge, U.S.:—Harvard University. Catalogue. 1874–75. 8vo. 1874. Catalogus. 1875. 8vo. Forty-ninth Annual Report of the President of Harvard College. 1873–74. 8vo. 1875. Trea-

Reports, Observations, &c. (*continued*).

surer's Statement. 1874. 8vo. Annual Report of the Trustees of the Museum of Comparative Zoology at Harvard College for 1875. 8vo. *Boston* [*U. S.*] 1876. The University.

Melbourne:—Philadelphia Centennial Exhibition of 1876. Official Record, containing Introduction, Catalogues, &c., and Essays and Statistics on the Resources of the Colony of Victoria. 8vo. *Melbourne* 1875. The Commissioners.

Paris:—Dépôt de la Marine. Annuaire des Marées des Côtes de France pour l'an 1876. 12mo. 1875. Annuaire des Marées de la Basse Cochinchine pour l'an 1876. 12mo. 1875. Annales Hydrographiques. 1874. 3, 4 Trimestre; 1875. 1–3 Trimestre. 8vo. Instructions Nautiques sur les Côtes de l'Équateur. 8vo. 1874. Côte Ouest d'Écosse. Partie 2. 8vo. 1874. Mer des Antilles et Golfe du Mexique. Partie 2. 8vo. 1875. Routier de l'Australe. Partie 2. 8vo. 1874. Renseignements sur les Archipels Marshall et Gilbert. 8vo. 1875. Eighty-nine Charts. The Dépôt.

San Fernando:—Instituto y Observatorio de Marina. Anales. Seccion 2ª Observaciones Meteorologicas. Año 1874. folio. 1875. The Observatory.

Acland (Dr.), F.R.S. The Relation of Modern Engineering to Public Health and Local Government. 8vo. *Oxford* 1876. The Author.

Ferrers (N. M.) An Elementary Treatise on Trilinear Coordinates. Third Edition. 8vo. *London* 1876. On Prof. Sylvester's Representation of the Motion of a free Rigid Body. 4to. 1869. On the Motion of a Mass of Water about a Moving Cylinder. 8vo. 1874. On the Motion of an Infinite Mass of Water about a Moving Ellipsoid. 8vo. 1875. On the Potentials of Ellipsoids &c. 8vo. 1875. The Author.

Greenhow (Dr. E. H.), F.R.S. On Addison's Disease, being the Croonian Lectures for 1875, delivered before the Royal College of Physicians. 8vo. *London* 1875. The Author.

Harris (John) Centrifugal Force and Gravitation. 6 parts. 8vo. *Montreal* 1875. The Circle and Straight Line. 8vo. 1875 (and Plates). A Review of Macaulay's Teaching on the relationship of Theology to the Science of Government. 8vo. 1874. The Bible read by the light of Science. 8vo. 1874. Spiritual Science and the Natural World. 8vo. 1876. Natural Philosophy and Divine Revelation. 8vo. 1875. Political Economy and Science. 8vo. 1875. The Author.

Prestwich (Joseph), F.R.S. On the Geological Conditions affecting the Water Supply to Houses and Towns, with special reference to the modes of supplying Oxford. 8vo. *Oxford* 1876. The Author.

"Preliminary Note on the Anatomy of the Umbilical Cord"*. By Lawson Tait, F.R.C.S. &c. Communicated by W. S. Savory, F.R.S. Received April 28, 1875.

[Plates 11, 12, 13, 14.]

I. *Its external Form and Method of Growth.*

The peculiar twisted appearance of the human umbilical cord has received much attention from anatomists, and has been the subject of much ingenious speculation. According to Velpeau ('Embryologie') the torsion begins as early as the seventh or eighth week, whilst Burdach has not observed it earlier than the tenth. I have repeatedly seen fœtuses, apparently of the twelfth and thirteenth week, in which no appearance of twisting was observable in the cord, though one of the most perfectly twisted cords in my possession belongs to a fœtus of certainly not more than thirteen weeks' development.

Velpeau attributes the twisting simply to the rotation of the fœtus. Schroeder Van der Kolk supposes that the blood flowing in the arteries exerts a backstroke influence on the pelvis of the swimming fœtus, thus determining its revolution in one direction or the other, as the arteries are to be found to the right or left of the vein. In order to dismiss this view we have only to recollect that the umbilicus could not in any way become a fixed axis, and that the mechanical arrangement of the heart, in the non-separation of its streams, would yield but a very weak impulse until very late in pregnancy. The revolution of the fœtus is not known to occur, though its occurrence is probable. Such revolution occurs in the spawn of the frog as early as the first segmentation of the black sphere; but then it is evidently the result of the necessity there is for an equal exposure of all parts of the embryo to the action of light and heat, just as the germinal spot is always uppermost in the bird's egg. No such necessity exists in the persistently included mammalian ovum, and the revolution of the fœtus cannot be accepted. If it did occur it is highly improbable that the revolutions could number only from four to eighteen, these being the ranges I have noticed in a large number of fully developed cords. Another objection to Schroeder's hypothesis is that, as a matter of fact, the arteries leave the omphalic ring nearly always below the vein and symmetrically arranged in relation to it. Their passage to one or other side of it is seldom apparent till the external dermal ring has been reached. Also I have seen the first revolution of the arteries pass from right to left, after which they suddenly bent on themselves and passed up the cord in an irregularly straight course, whilst the vein maintained the normal spiral. Further, I have seen the arteries reverse their course about the middle of the cord, though the vein maintained the uniform spiral.

Sir James Simpson ('Edinburgh Medical Journal,' July 1859) was of opinion that at the time of the commencement of the torsion the right iliac artery appears more like the continuance of the aorta than the left, the latter appearing more like a branch, the right having, therefore, a stronger blood-stream than the left; it would thus influence the fœtus. This supposition is ingenious; but I cannot find any fact which will support it. I have examined several fœtuses from the ninth to the sixteenth week without being able to discover any difference in the right and left iliac arteries. Such difference, if it exist, should continue during the growth of the cord; and I have entirely failed to find any evidence of it in any of the large number of fœtuses I have examined. Moreover, it seems greatly contradicted by the fact established by Hecker, that the twist is once to the left for 3·5 times to the right. Further, are we to suppose that in the cases of well-matured children in whose cords there are no twists, or only very slight ones, the embryo has continued perfectly still in the cavity of the amnion?

---

* See Proceedings, vol. xxiii. p. 498.

Neugebauer ('Morphologie der menschlichen Nabelschnur,' Breslau, 1858) explains the rotation by the pressure of the blood-stream on the walls of the vessels. The umbilical vein, he states, has a greater area than the two arteries together, and is more distended, the pressure diminishing its growth in length, whilst that of the arteries is uninterfered with, and the natural arrangement must be spiral. Whatever be the explanation, it is a fact which my injections and dissections have established beyond dispute, that the arteries have a greater length than the vein in very many cases, but it is not true in all.

In some cords the vein is longer than the arteries, for it remains spiral whilst they go almost straight. In others the vein continues persistently and regularly a definite spiral direction, whilst both arteries course over it first in one direction and then excentrically in another, sometimes even turning back over their first course and presenting a varicose appearance on the cord, to return again to their normal direction. Neugebauer states what is in strict accordance with my own experience, that irregular twistings are very common on the arteries but very rare on the vein. I have never seen one on the vein.

Neugebauer further believes that the reason the majority of cords are twisted from right to left lies exclusively in a dissimilarity in the size of the arteries. He has found (in agreement with Simpson) that the right artery is larger than the left. Occasionally, he states, the left is the larger of the two, and then the twist is reversed.

Hyrtl ('Lehrbuch der Anatomie des Menschen') states that the left artery is usually the larger of the two. I do not see, in the writings of either of these two authorities, any details of the method of examination of their specimens.

My own method has been to remove the whole thickness of the abdominal wall from the base of the bladder up to and including the omphalic ring, along with a piece of cord. This I place in my freezing-machine, and cut from it a number of consecutive sections, examining at intervals, by careful measurements, the two arteries. I have seen no reason to agree with the conclusions of Simpson and Neugebauer. Even if their position were established it could only refer to the contracted condition of the vessels after death, and this would afford no accurate clue to their relative sizes during life. But even if it did it would not explain, as I shall try to show, the spiral growth of the cord.

In the investigation of this subject my first endeavour was to ascertain which of the three tubes in the cord had the greatest influence in maintaining the spiral, either before the cord was separated from its connexions or after. If, while the cord was still attached to both mother and child, I passed a needle through the cord close to the child, so as to isolate the vein, and then compressed it against the needle, I found that the spiral was completely maintained. On the contrary, if I compressed the arteries and cord together towards the placenta, the cord emptied and became flaccid, losing its spiral appearance. This was the case very markedly in the instance of a cord which is the most perfectly spiral in my possession. On distention by injection it showed a complete helix in the remarkably short distance of an inch and an eighth with a perfect lumen through the helix of three sixteenths in diameter. In this cord the arteries coiled together within the helix of the vein. In no cord which I have injected, and in which the twist was evident at all, has it not been as evident that the vein was the main factor in the twist. I have established this by distending, in a well-twisted cord, the three vessels alternately with water. Distention of the vein induces the complete spiral of the cord. Distention of one artery has little or no effect, and distention of both arteries in no case equalled the results obtained by distending the vein. I have injected both arteries with some slightly resisting material, as stiff size, and after it has set I have distended the vein with plaster of Paris, and in every case it has become evident that the chief spirality lies in the vein. Injection of an artery with plaster of Paris and allowing the whole cord to dry seldom produces a well-marked spiral in any part of the cord, and never throughout its whole length. A similar proceeding with the vein will produce a perfect spiral throughout the whole length of any cord which has the twist running through it.

Neugebauer also found that blowing up the vein produced more marked twisting of the cord than blowing up the arteries. In one of my specimens injection with plaster has done so over a length of three feet, and the dried arteries are seen coiling round it; yet distention of these arteries by water did not produce any spiral at all. In any regularly spiral cord the arteries will always be found on injection to be within the helix, a point which is very suggestive that the vein is the chief factor in the production of the twist. In such cords as those in which the whole development and the spiral are evidently deficient (and this has no relation whatever to the development of the child), the arteries are to be seen on the outside of the imperfect helix, and this greater length has to be accommodated by twistings and reversions. But even in such a cord sections are to be seen where the spiral becomes complete, and then the arteries take their normal place within the helix.

Injection of one or both arteries by plaster, with subsequent drying, does not produce a spiral even in cases where the cord has shown a very marked spiral when the vein has been previously distended with water.

When the spiral is faintly marked but the cord long, and the arteries not very much, if at all, longer than the vein, the spiral will be found always at the end near the fœtus. Thus in one specimen, which is very typical of this class, there are three well-marked helices occupying the six inches of the cord at the fœtal end. One artery was successfully injected, and it is seen to occupy an almost straight course in the middle of the helices, the uninjected artery accompanying it closely, whilst further on they are both seen to follow, with only one reversion or doubling, the almost straight course of the vein.

This last fact makes it very evident that the growth of the spiral is directed by some mechanism at the fœtal end of the cord, and not by any hypothetical revolutions of the fœtus.

From the appearances of some cords it would also seem as if the spiral growth of the cord became interrupted for a short time, or even reversed, and then that it resumed its original direction.

In the first and fourth volumes of the 'Encyclopædia of Anatomy' some interesting quotations are given by Vrolik and Mr. J. Hart. Vrolik gives some cases where the vessels ran from the fœtus to the placenta separately, and not twisted in a cord. He also mentions that extreme shortness of the cord is generally accompanied by ectopia of the abdominal viscera, indicating an arrest of development at an early period of embryogenesis. Rudolphi states that the umbilical vein is persistently double in the Quadrumana of the new world; but I cannot anywhere find a statement as to whether, in such a case, the cord is twisted or not.

I think we may conclude from some of these facts that both the growth of the cord and its spiral direction are due to some mechanism at the omphalic ring, and that probably that mechanism is in a most immediate relation to the umbilical vein.

Further, I think it certain that the greater part of the spiral, and the closest coils of the spiral, are formed during the later months, or even weeks, of gestation. Thus in cords which are deficient in the spiral it is always most marked near the fœtus; and in one which I have already alluded to as the most perfectly spiral cord I have seen, the helices were complete in an inch and an eighth near the child, whilst they gradually opened out towards the placenta, so that the last was nearly three inches in length. This could not be the case if the twisting were due to the rotation of the fœtus during early embryonic life, as then we should expect that the spiral would be uniformly spread over the cord, if, indeed, it would not be most marked near the placenta. Neugebauer says that the spirals have a uniform length, with the exception of those close to the placenta, which are almost invariably longer.

In his 'Cellular Pathology,' Professor Virchow gives a drawing of the umbilical cord, and the following description of its vessels:—"The only capillary vessels which are found in the whole length of the umbilical cord of a somewhat developed fœtus do not extend more than about 4 or 5 lines (in rare instances a little further) beyond the abdominal walls into that part of the cord which remains after birth. The further up this vascular part extends the greater the development of the navel. When the vascular layer is prolonged but a very short distance the navel is depressed. The capillaries mark the limits of the permanent tissue; the deciduous portion of the cord has no vessels of its own."

I have made many very careful injections of fœtuses of various ages in order to verify this observation. For a long time I was quite unable to do so, and I had the impression that Virchow had mistaken a part of the dermal ring, with the epithelium rubbed off, for a part of the true substance of the cord. From a large number of observations I have found that the dermal ring runs on to the cord in a camb-like shape (Plate 11. fig. 1)—that is, that the length of the ring is unequal all round, the greatest length corresponding generally to the position of the vein at the upper part of the ring (Plate 11. fig. 2). This, however, is not constant. At this point the capillary plexus is shown in Virchow's drawing; and from a completion of Virchow's partial observation, it seems to me that in this arrangement we have the immediate mechanism of the spiral growth of the cord.

The necessities which have evolved it are probably those of the erect position of the human animal, by which the fœtus, resting on the brim of the pelvis, might compress the cord to an unsafe extent. This compression would be better resisted by a spiral cord than by a straight one. Further, the form of the human uterus, and the occurrence of single gestation as a rule, favour movements of the fœtus in all directions; so that it is well known to the tocologist that the fœtus frequently changes its position, though nothing like revolutions are known. During these movements, however, the child might make one or more revolutions, and these might have a disastrous result if the cord were straight; but it being already twisted, a few revolutions in the direction of the twist could do no harm in the way of occluding the vessels, nor could a few revolutions in the direction of untwisting it be at all likely to be hurtful.

John Goodsir has shown how thoroughly the spiral runs through all growth, and how perfectly it is seen in joints. It is the universal direction of growth in plants and shells, and may yet be shown to exist in structures where little suspected. If we accept the doctrine of continuous descent, we can be at no loss to account for the presence of a spiral in the umbilical cord, the most lowly organized structure in the human economy. If we do not accept that doctrine as more than an hypothesis, the spiral growth of the cord may yet be advanced as an argument in favour of its establishment. To this end its history must be carefully worked out, and to this I hope to be able to make a contribution in another note.

Virchow is the only author whom I have found to state that capillaries pass from the structures of the child into the substance of the cord; but there can be no doubt that he is correct.

I injected a large and fully developed still-born child with a strong solution of Berlin blue in size, under the pressure of 350 millims. of mercury. Every organ was completely injected and the liver had given way.

At the fœtal attachment of the cord, and running upwards from the line of demarcation, was an arrangement of small capillaries. These were visible all round the attachment of the cord, but at some parts were not more than a millimetre in length, while elsewhere they were 8 or 10 millims. They did not seem to form loops, but to run straight out from the dermal ring along the cord and immediately under its surface.

There were five points at which the exaggeration in length was very marked, three of these corresponding to the region of the vein, and one to each of the arteries (Plate 11. fig. 2).

It will be seen from this that the nutrition and growth of the cord, supposing them to be in part due to this arrangement of blood-vessels, must be unequal—that is, that one side will grow somewhat more than that opposite. This, of course, is certain to result in a spiral; and this principle of unequal nutrition I hope to be able to demonstrate in further communications as a great principle in all organic spiral growth.

A further consideration of the arrangement and function of this plexus is given in another division of this note.

II. *Its Covering.*

The naked-eye appearance of the covering of the umbilical cord needs no minute description here. Like all other serous surfaces, it is smooth and glistening, and it is continuous with the epithelium of the amniotic surface of the placenta; but a very sharp line of demarcation exists between the epithelial surface of the cord and that of the skin covering the omphalic canal.

This line, however, is only a naked-eye appearance; for staining and examination by the microscope show that the layers are continuous.

I have not seen any difference between the structure of the two epithelial surfaces, nor do I think that there is much difference in their function.

The epithelial covering of the cord is said to be derived from the amnion; but this is a loose method of description which has yet to be substantiated.

In all the microscopic examinations from which descriptions are taken in this paper, the sections have been made by my freezing section cutter, from fresh tissue unless otherwise stated; and they have been submitted to various staining-processes by the action of litmus, hæmatoxylin, red cabbage, &c., as described in Humphrey and Turner's 'Journal of Anatomy and Physiology,' May 1875. The lenses used have been a half-inch and a quarter-inch objectives of Natchet, with the corresponding eyepieces 1, 2, and 3, and an immersion sixteenth of Hartnack.

To obtain pieces of the epithelial surface of the fresh cord of any size and of sufficient thinness to see the surface transparently was a matter of considerable difficulty. I first of all tried freezing the fresh cord while pressed flat against a piece of glass, tearing off the glass and then cutting off the flattened surface. To the fact that the glass removed with it a great part of the epithelium I owe a most important though accidental observation. I further found that first smearing the glass with glycerine prevented the cord becoming intimately attached to it; and by carefully washing off the glycerine by distilled water I obtained a perfect epithelial surface free from disturbance. This I examined after being treated in various ways. Soaking the section in an ammoniated solution of litmus or hæmatoxylin and reducing the colour by washing it in a ·004 per cent. solution of nitric acid, I found that the epithelial layer was single and composed of irregularly polygonal cells, regularly nucleated. These cells were bedded in a fibrillar matrix, very thin, and in which no special structure could be discovered, and which is certainly only a slightly condensed arrangement of the canalicular system on which the cells lie. Virchow has described the subepithelial tissue as a "somewhat denser dermoid layer;" but I have failed to see any such analogy. The fusiform nuclei of the canalicular tissue are to be seen (Plate 11. fig. 6) immediately under the single layer of epithelium, lying in the direction of the long axis of the cord. These epithelial cells differ from similar cells on the fœtal surface of the placenta and amnion only in being somewhat less regular in size and arrangement; and, indeed, in these points they differ to a considerable extent on various parts of the cord itself, for they are slightly larger and more regular near the fœtus than near the placenta. That there is only a single layer of cells is a point on which I am satisfied; for I have stained the whole layer removed on the glass, as I described above, and I have never been able to focus one cell above another.

Further, in a microscopic section of a fresh cord stained with hæmatoxylin the epithelial covering may be seen to be turned over. The nuclei are stained; and when they are brought into focus under a quarter objective, it requires only about the thirtieth part of a revolution of a fine screw adjustment to bring the subjacent fusiform nuclei into clear definition, that screw having 56 threads to the inch. The thickness of the layer is therefore certainly not more than $\frac{1}{1700}$ of an inch.

For the silver treatment I have employed a solution of lactate of silver with the addition of some free lactic acid, and I have found the results more definite than those given by the employment of a solution of the nitrate. The method is advised by Serge Alferow, of Charkow. This treatment displays an irregularity of size and arrangement of the cells such as I do not see in those of any other epithelial surface, and which I think must be due to the singleness of the layer. It is not due to my method of treatment, for I have seen it in small pieces which I have snipped off by scissors, without freezing on glass. The intercellular substance takes on the characteristic brown colour (Plate 11. fig. 3), and between certain cells slight ganglioniform enlargements of this colour are to be seen in great numbers—the stomata spuria of Klein. I am in as great doubt as that author whether these dark spots have any thing to do with the subjacent canal-system. They may have; but I have seen nothing as yet which convinces me that they are other than mere extensions of the peculiar intercellular substance which first takes up the argentic stain. That this stain is more than a mere filling up by the darkened solution of intercellular gutters must be the conviction of any one who works to any large extent with silver fluids; for in other tissues it may be seen to affect nuclei with avidity, as notably, in my own experience, it does in the placenta and in the ovary. Certain groups of cells in epithelial surfaces are seen to take up this colour without apparent meaning; but this is much less frequent in the cord than in the amnion, &c.

The groups of small darkly coloured cells or nuclei which are now admitted to mark the stomata of serous membranes are numerous on the cord; but I am bound to state that my experience of them had to be extended to other membranes before I could admit for them the interpretation which they had in the opinion of others, and notably of Koster. They are unquestionably the orifices of the vast system of canals which forms the basis of the cord and upon which it solely depends for its nutrition. Round their orifices, or within their entrance (I have not yet decided which), are to be seen these small darkly shaded cells. I doubt if they are endothelia. I believe that rather they are young epithelia in growth; that, in fact, these stomata are the points of growth and extension of the epithelial layer of the cord, and that the groups of darkly coloured cells of larger size to which I have already referred are the same in further progress. It certainly is the fact that round the stomata the uncoloured cells are often of much smaller size than they are at a little distance away. At a few points I have been fortunate enough to see these stomata leading directly into a canal, into which the staining-fluid seemed to have permeated, and therefore rendered it distinct.

But the absolute proof is to be found in a few preparations where the epithelium has been partly removed by the accident I have already described. Thus at one spot I saw the edge of the coloured epithelium curled up, displaying the naked (Plate 11. fig. 3) canals where it had been removed; and there the stomata could be seen leading directly into the canals where the epithelium was still *in situ*. The canals will be seen branched in all directions, with large central spaces. At one point at least I certainly saw such an enlargement correspond exactly with a true stoma; and though much remains to be done in this direction, it seems to me more than likely that each of these lacunar enlargements may be at any or at some time the site of a stoma.

The number of stomata on the surface of the cord is certainly very much less than the number of lacunar enlargements in the subjacent canals. But it does not seem probable that the sites of the stomata are constant. They seem rather to be in process of change, formed by loss of epithelium and closed by its regeneration. This is not much more than speculation; but it would explain some curious facts hitherto not explicable.

I have already mentioned that there seems to be some difference in the details of the arrangement of the epithelium at the fœtal end of the cord from that at the placental end. Perhaps these differences are accidental to the one cord examined for this purpose; but even there they are marked enough to be mentioned. The cells are smaller and more irregularly jointed, and more especially they seem elongated in the direction of the long axis of the cord. They are not so well marked nor so numerous, and the darkened groups of small cells are not much seen. The whole structure gives the impression as if it was older than that nearer the fœtus. Thus in the canals and in the stomata are to be seen regular rows of minute refracting globules, visible only under very high powers, the nature of which I have been unable to make out as they are seen only after deep silver staining.

III. *Its Substance.*

Since the publication of Wharton's 'Adenographia' (London, 1656), the name of "Wharton's jelly" has been retained for the proper substance of the cord.

Although the substance is in no sense gelatinous, the name is convenient from its traditions, and it is likely to be retained. The jelly-like appearance is due simply to a preponderance of fluid contained in alveoli. Virchow dismisses the chemical character of this fluid by saying that it contains mucin. So far as I have gone, however, it contains much more definite compounds, and seems closely to resemble the liquor amnii, if, indeed, it be not that fluid itself. This point requires much more investigation than I have yet been able to give to it. Virchow regards this tissue as ranking with embryonic subcutaneous tissue and the vitreous humour. I am not yet in a position to give an opinion on this relationship, though I think it possible.

This alveolated tissue is divided, throughout the whole length of the cord, into three columns, one of which surrounds each blood-vessel. The divisions between these three columns are not visible to the naked eye, but they become very perceptible when the tissue is injected in the manner to be immediately described. When the nozzle of the injecting-apparatus is inserted into the tissue of one column, the fluid will be found to travel along that district only, unless such pressure is used as produces rupture of the limitation of the column. The injection will be found to surround the blood-vessel of its district with great uniformity (as shown in Plate 11. fig. 4), but the injection will never be found to encroach upon the walls of the vessel. The limitation can scarcely be said to be membranous; for if the adjacent tissue of two columns be injected, the line of demarcation where they touch cannot be made out. It seems to depend upon the absence of communication between the canals of the two columns. This is a most interesting fact bearing on the nutrition of the blood-vessels.

Virchow describes the proper substance of the cord as consisting of "reticulated tissue, the meshes of which contain mucin and a few roundish cells, whilst its trabeculæ are composed of a striated fibrous substance in which lie stellate corpuscles. When a good preparation has been obtained by treatment with acetic acid, a symmetrical network of cells is brought to view, which splits up the mass into regular divisions."

Kölliker considers the substance to be "immature connective tissue with stellate anastomosing cells." Weisemann thinks "it corresponds to the skin and subcutaneous tissue in arrest of development." But it seems to me, however probable their explanations of the biological relations of the tissue may be, that their descriptions of its anatomy are only partially accurate and far from being complete. The facts are that the striated fibrous tissue is composed of the collapsed walls of numerous canals of which alone the proper tissue of the cord is made up. When only partially emptied some of them appear like stellate cells, and therefore they give the deceptive appearance of there being a matrix in which Virchow's "connective-tissue corpuscles" are imbedded. In the lacunar spaces of the system oval nuclei are imbedded in the walls of the canals. In a large number of observations I have never seen these nuclei alter their shape and position.

Before detailing the results of my observations on these canals, it will prove more satisfactory if I describe my methods of preparing the specimens observed. First of all I may say that I have in no instance drawn a conclusion from observations made on a cord otherwise than perfectly fresh, unless it is distinctly stated to the contrary. I have found the examination and treatment of tissue which has been subjected to hardening reagents so unsatisfactory that I have quite discarded it.

All my sections are made by the freezing process (described in Humphrey and Turner's Journal for May 1875), so that sections of the perfectly fresh cord of about $\frac{1}{600}$ of an inch in thickness have been examined. These have been subjected to various treatments—as simple clearing by glycerine, destruction by acetic acid, staining by silver lactate, and by my various indifferent staining-fluids, hæmatoxylin, litmus, cabbage, &c. (also described in Humphrey and Turner's Journal).

My injecting-apparatus is so arranged that it acts automatically when set at work. The tissue injected and the whole apparatus is surrounded by a current of warm water, the temperature of which is registered. The injecting force is supplied by compressed air admitted directly to the surface of the injecting-fluid, and the pressure is registered by a manometer. The nozzles used vary in diameter from 1 to 4 millims. The fluid used is a ten-per-cent. mixture of Seitels's Berlin blue suspended in firm size. This does not stain the tissue because it is not in solution, yet its granules are too small to be seen by any power of lens in my possession. That it is not in solution is certain from the fact that it is completely removed from the fluid by adding some albumen and boiling. Similar but not so satisfactory results may be obtained by Davies's granular carmine; but here the granules are too large to enter the canals, save under such pressure as produces frequent extravasation.

One disadvantage of the Berlin blue is that it contains a little free acid, and must do so to remain visible. After a short time this acid destroys the colouring of the stained nuclei; so that, save in an almost perfectly fresh specimen, it is impossible to demonstrate the relations of the nuclei to the canals when distended by the injection.

The method of injection of these canals is apparently very rough. It consists simply in inserting a small nozzle superficially into the substance of the cord over and parallel with the course of a vessel, tying it in, and injecting under a low pressure of 50 or 60 millims. of mercury.

Schweiger-Seidel made the very obvious objection to this (Recklinghausen's) method that any appearances presented by it would be simply those of extravasation. Such was my own belief when I first tried it on the cord; but very short experience showed me that the result was a regular and uniform injection of a system of canals, and that extravasation was very rare and always limited to the immediate neighbourhood of the wound in the cord. With the whole apparatus at a temperature of 47° and a pressure of 60 millims., I have injected a column of the cord for a distance of 9 inches in about half an hour. The injection travels rather more rapidly in the direction from the child to the placenta than in the opposite direction.

I have repeatedly seen minute streams of the blue injecting fluid flowing from the surface of the cord into the water surrounding it, even at as low a pressure as 55 millims., with a nozzle only 1 millim. in diameter; yet at a pressure of 350 millims. I have not produced a rent in the surface of the cord, though I have produced numerous extravasations into the alveoli and into the neighbouring columns. The appearances when these canals are distended are well shown in several of the drawings, but especially in Plate 11. figs. 5, 6, and Plate 12. fig. 14, in the first of which they are seen to run up close to the muscular coat of the artery. Transverse and longitudinal sections of the same piece of the cord show that they are stellate in every plane, and that they intercommunicate in every direction; but their processes are slightly longer in the long axis of the cord than in any other. This, however, is not constantly evident.

Recklinghausen regards these canals as wall-less spaces between the anastomosing cells, simple interspaces in the connective-tissue basis substance ("Ausgrabungen in der Bindegewebs-Grundsubstanz"); but that this is not so my own observations, substantiating those of Koster, I think completely established. It is best proved by preparations of the termination of the injected district, where the blue colour may be seen running into the processes of the so-called stellate "connective-tissue corpuscles," contrasting with the complete occupation by the colour of every thing but the alveoli*. It is in these alveoli exclusively that I have found the round migratory cells.

Henle thinks that the anastomosing cells may be the foundation plan for blood-vessels ("Gefässanlage"), such as are seen in the umbilical cords of all mammals but man. So far, however, as I have yet seen the vessels which extend over the mammalian cord are chiefly on its surface, as I have already mentioned they are to a limited extent at the fœtal insertion of the human cord; but this point is one for further research. It is scarcely possible, however, to regard a system of canals which constitutes *the whole tissue of the cord* as a representative of blood-vessels, otherwise it must somewhere be seen as an almost erectile tissue.

Fohmann has asserted that he has injected a complete system of lymphatic vessels in the cord by quicksilver; and though Virchow thinks that his material has permeated the alveoli, and Hyrtl that his lymphatics are mere chasms in the tissue, I think it possible that he really has injected these canals, but that from his inability to make sections which would retain the quicksilver in the tissue, he has not demonstrated the facts of his system. This difficulty is obviated by the use of size and Berlin blue.

Staining with silver lactate (1 in 800, with slight excess of lactic acid) leaves the canals as clear white spaces (Plate 11. fig. 3), but gives a decided brown edge to them, which shows that they are walled. Their general appearance after this treatment closely corresponds to that seen after their injection minus the extreme distention. I have never seen any appearance of endothelia in these canals; but there is a very constant relation of nuclei to their walls in the lacunar spaces. These nuclei, when examined by a power of 200 diameters, seem to be fusiform (Plate 11. fig. 8); but when examined by a sixteenth immersion-lens, they are found to be of a regular oval shape, and to have a nucleolus which is very small in proportion to the mass of protoplasm (Plate 11. fig. 7). They are not always solitary, and occasionally one large nucleus may be seen associated with a number of smaller structures which seem identical. These nuclei are readily shown by acetic acid; but by such treatment their relations to the lacunæ are destroyed. They readily take up the colouring-matter of an indifferent solution of hæmatoxylin; but I have not yet been able to colour them with litmus. These nuclei are constant.

---

* This is also shown in silver-stained sections (Plate 11. fig. 3), where the walls seem indicated by an increase of colour.

In the alveoli, which lie between the anastomosing branches and also between the lacunæ of the canals, are sometimes found numbers of round cells. They do not readily take up hæmatoxylin, at least I have not often been enabled to find them by means of that stain, but they readily absorb the litmus colour. When examined by a quarter they appear like round free nuclei; but if examined very carefully, or with a sixteenth, they are seen to have a thin layer of uncoloured protoplasm round them. They are in fact cells (or nuclei) in which the nucleus (or nucleolus) is disproportionately large for its envelope: they are not constant. In some cords, especially when removed from large children, they are found very scantily; whilst in the cord of a small eight months' child (Plate 12. fig. 9) I found them to be extremely abundant. They are also, as in this instance, found far more numerous in some parts of the cord than in others, and in one district of the cord than in another. They are most abundant close to the umbilicus, and in the districts in which the capillaries are seen. They are certainly free in the alveoli; for I have seen them wandering and exhibiting amœboid movements on the warm stage, after having taken up the litmus colour. I have never seen the lacunar nuclei exhibit any movements, nor have I ever seen any appearance as if they multiplied by division. These round cells may not be confined to the alveoli, however, as they seem scattered over the tissue in the uninjected cord. In the injected cord I have seen them in the alveoli only. In sections taken near the umbilicus they are seen to be most numerous in the vicinity of a small capillary which ran up the cord certainly to as far as half an inch from the ring. Here they are also seen to be of larger size than elsewhere (Plate 12. fig. 11), and to appear close to the mass of blood-corpuscles which, as a clot, occlude this capillary. My inference is that they originate in this neighbourhood (to be afterwards more carefully described) and migrate throughout the cord. They do not ever appear as if they multiplied by division. The walls of this small vessel had no muscular fibre, but seemed to be formed merely by a condensation of the canalicular tissue.

Koster regards these two forms of cells as the same, and differing only in position. But he has evidently neither applied high powers nor delicate stains to them, so as to discover the presence of a nucleolus in one and its absence in the other. The different actions on them of litmus and hæmatoxylin seem very decisive as to their being different structures, and probably having different functions. They are also quite different in size and appearance.

Koster states that he has seen the nuclei of the lacunæ send fine shoots into the branching canals. This is only an optical delusion, which is dispelled by the use of the high power immersion-lens.

I conclude, therefore, that the proper tissue of the cord is entirely canalicular. How the canals are formed, and what relation their nuclei have to their growth and nutrition, has yet to be determined. It is, of course, more than probable that the explanation of the growth of the stellate corpuscles advanced by Virchow, Aeby, and Eberth is applicable to the lacunar canals; that is, that they are the result of cell modification, the body of the corpuscle expanding into a membrane for the formation of the lacuna and its processes, whilst the nucleus remains for nutritive reproduction. This, however, I am not yet prepared to accept, but it might explain one function of the round cells.

Koster speaks of having seen "in silver-stained sections irregular or interrupted lines showing through the white canals, which remind us of the luting substance between two epithelial cells;" but I have not been fortunate enough to have seen any of these lines.

I agree with Koster that it is probable that the canals communicate directly with the amniotic cavity by means of the stomata; but, beyond having satisfied myself that the stomata lead directly into the layer of canals immediately under the epithelium, I cannot say I have traced the continuity. I believe the minute streams of injection-fluid, which both Koster and I have seen flowing from the surface of the injected cord, have come from the stomata, but I have not yet caught the fact in a section. Koster makes a similar confession.

In one point I am in disagreement with all observers with whose work I am acquainted, in that I am certain that the nuclei of the lacunæ are not loose in the cavities but are adherent to the wall at one point. The double method of injection and staining proves this conclusively.

By no kind of process which I have employed, in quite a large number of observations, have I been able to discover any thing in the least degree resembling a nerve-fibre in the substance of the cord; and I have failed to substantiate Kölliker's observation of the entrance into it of branches from the hepatic plexus.

When one of the columns of the cord is injected the canals will be seen, as I have already said, to run up to the muscular walls of the blood-vessel of the column, but I have never seen a canal enter the muscular tissue.

It is then quite easy to discriminate between the canalicular and muscular tissue; but in the unprepared, or in the stained section, it is impossible to decide where exactly the muscular fibre begins, especially if the blood-vessel has been distended, for then the layers of canalicular tissue immediately outside the blood-vessel are stretched so as to be parallel in direction to the general course of the muscular fibres. It will be seen, therefore, that the whole column of the cord constitutes the external coat of the blood-vessel, and also the substitute for the *vasa vasorum* which are seen in other arteries.

I have already described an arrangement of blood-vessels at the root of the cord when speaking of its method of growth, but something more must here be said on this point. When the nozzle of the syringe is tied into the still attached cord an inch or two from the fœtal insertion, with the stream towards the fœtus, the injection is made to travel with some difficulty, and it is always found to terminate in a sort of cone outside the blood-vessel, the apex of which is just within the dermal ring (Plate 12. fig. 13). At this point it seems impossible to get the injection to travel round the blood-vessel as it does elsewhere in the cord—that is, I have failed to get it to enter the subcutaneous tissue on the other side of the omphalic ring; and, as will be seen in the same specimen, I have been equally unable to get it to travel from the subcutaneous tissue into the substance of the cord even under so great a pressure as 500 millims.

When the extreme apex of the cone obtained by injecting the substance of the cord near the ring is examined by sufficient power, it will be seen that the injected canals (Plate 12. fig. 14) run up to and border immediately upon the nucleated fibrous and muscular tissue which constitutes the omphalic ring. I have failed to inject any capillaries from the tissue in this way.

It is clear, then, that there must be some special arrangement for the nutritive supply of the substance of the cord, as it does not obtain any assistance from the umbilical vessels; and mere stomatic absorption, though I think it undoubtedly plays a most important part in the nutrition of the cord, could hardly be considered as sufficient to do the whole work.

When the capillary plexus running from the dermal ring (already described) has been successfully injected, I have found that a peculiar vascular arrangement is also displayed in the centre of the cord, lying in the firm nucleated tissue which forms the omphalic ring, and to which is due unquestionably not only the process of growth of the cord, but also in great measure its nutrition and the processes of closure of the vessels of the ring, and the removal of the stump by inflammatory ulceration.

The basis of this arrangement is a peculiar sacculated sinus, a mere excavation in the fibrous tissue, as I have been quite unable to demonstrate any definite wall for it. It seems to have a spiral arrangement; for in section (Plate 13. fig. 15) it appears and disappears as only a screw could. It extends from the omphalic ring at least 12 millims. up into the true substance of the cord, giving off at short intervals thick trunks which rapidly break up into capillaries. Nowhere in this peculiar vascular arrangement of the cord, either central or superficial, have I seen the capillaries turn up in loops as if to go back. They open, as I have seen in innumerable instances, directly into the canalicular system; and it is possible to inject a large extent of all these districts of the substance of the cord by placing a nozzle in the vein and first injecting the fœtus. After that has been accomplished, the capillaries, and finally the canalicular tissue of the cord, can be seen filling. In one section (Plate 13. fig. 15) the capillaries were seen opening into a limited district of the canalicular tissue, which evidently was somewhere near the apex of its cone.

The injected tissue was in immediate relation to the walls of an artery and of a vein. I believe that under favourable circumstances I may yet succeed in this way in injecting the whole substance of the cord.

The point of origin of this sinus I have as yet failed to work out; but I conclude it comes from the intercosto-lumbar arteries, as the injection of the cord does not appear until the skin of the abdomen is perfectly blue.

The superficial layer of capillaries may also be seen entering the canalicular tissue of the cord. They lie immediately under the surface of the cord.

It is quite evident that the analogy between this capillary supply for the cord and the Haversian system of canals in bone is complete. The Haversian canals admit red corpuscles, but the stellate lacunæ admit only liquor sanguinis. So it is with this nutrient arrangement of the cord; and not only is the function of the stellate canals of the cord identical with that of the lacunæ and canaliculi of bone, but their anatomy is the same minus the deposit of the salts of lime which occupy the alveoli. In the cord the place of the salts of lime is occupied by water containing some organic compounds.

In one cord I found a capillary extending nearly an inch from the omphalic structures, and which, when its surrounding and concentric layers of nucleated canals were stained with hæmatoxylin, very closely resembled an Haversian system (Plate 13. fig. 16). This is probably the continuation of the central sinus, as it does not appear to have a definite wall, and it lay about the middle of the section.

As yet I have not been able to demonstrate this vascular mechanism in any but perfectly fresh and mature children, because the friction to be overcome in order to make the injection pass round the front walls of the abdomen is so great that it requires a greater pressure than the liver will stand in immature children, which generally have been dead some time before they are injected.

IV. *Its Vessels.*

In all previous descriptions it seems to have been taken for granted that the umbilical vein and arteries are identical with blood-vessels elsewhere; but I have already pointed out some important differences, and I have now to describe some others.

When the arteries and vein of a cord which has been removed from a mature and living child are examined, the arteries are found contracted to a very small size, and the vein is also found to be much contracted. The introduction of a tapering probe into the canal of an artery or of a vein shows that it can be readily dilated; and the forcible distention of the whole tube with water may be made to enlarge the diameter of the tube as much as four or five times. In the vein the possible distention is even greater; but in both there is a limit to it, and the walls are so strong that they resist a pressure of 800 millims. The distention is quite equable, and never presents any sacculations.

The proper tissue of the vessel is made up of the ordinary fusiform fibre-cells with their characteristic rod-shaped oval nuclei, the external coat being, as I have already shown, the canalicular tissue of the district proper to each blood-vessel. To the arteries there is certainly no inner or endothelial coat, though when the vessel is contracted, the inner fibres being pressed into folds by the contractions of the outer layers, their nuclei present at the apex of the fold a very deceptive appearance (Plate 14. fig. 25). Staining with silver or hæmatoxylin, however, gives the most decided indications of the absence of endothelium in the arteries, but in the vein it is probably present.

When a section is made of a fresh cord, removed from a mature and living child, in which one artery has been distended and the other left untouched, it will be seen that the contraction produces an arrangement of folds somewhat resembling what takes place in the closure of the œsophagus. The inner layers contract; but the outer layers seem to contract still more, so that the internal fibres become bent on themselves and form rugose prominences, which almost meet in the middle of the lumen of the tube (Plate 13. fig. 20) In the vein the muscular wall is much thinner, and this folding of the inner walls is not seen.

This does not take place in any other artery which I have examined for the purpose; at least, if it does so it becomes undone after death; but I did not find it in the carotid of a guineapig divided and examined immediately after death.

This extraordinary power of contraction of the umbilical artery is due to three conditions—the exceptional thickness of the muscular layer, the absence of any restraint by a firm external or any internal coat, and a peculiar arrangement of the external bundles of muscular fibres.

In the distended artery, examined after the addition of acetic acid, or after treatment by hæmatoxylin or silver lactate, the rod-shaped nuclei are seen to lie all in parallel directions, which are concentric with the lumen of the tube. In the contracted artery it is different. The fibres are seen distinctly to be arranged in bundles, and these bundles have different directions. Some are seen to be cut across, whilst others can be traced passing downwards through the section and ending on the lower surface. When a very thin section is made, stained, dried on the slide, and mounted in balsam or dammar, here and there two layers of bundles are seen, one immediately above the other, crossing one another like the limbs of St. Andrew's cross. Again, two sets of bundles may seem to be arranged like the webs on the shaft of a feather; longitudinal sections show this still better. Prolonged exposure to the action of acetic acid shows, in a longitudinal section of an artery, that the muscular fibres are arranged in bundles, the directions of which occupy a double spiral (Plate 13. fig. 17), somewhat like that carefully described by Dr. Bell Pettigrew as being the arrangement of the fibres of the heart. Silver-staining also demonstrates this. I have made a diagram of this arrangement (Plate 13. fig. 18), and it may be fairly well illustrated by the way in which a ball of twine is cast on the spindle. If the hole through which the spindle has been passed be supposed to represent the lumen of the artery, a distention of that aperture would, if the string were elastic as the fusiform fibres are, drag the string into a uniform direction concentric with the hole. There can be no doubt that such an arrangement, especially in the external bundles, where it seems to be most marked, would be of great mechanical advantage in the closure of the vessels.

One makroscopic fact is certainly in support of this view, which is that the length of an artery in the umbilical cord is very perceptibly diminished after its distention.

It remains a very interesting point to consider whether this spiral arrangement will not be found to exist in other arteries as well as in those of the umbilical cord. Dr. Beale figures it as occurring in the longitudinal fibres of the aorta of the horse.

In support of my statement that there is no endothelium in the arteries of the cord I may detail the following observations.

In the case of the vein silver-staining reveals no difference in the arrangement of the inner surface before and after distention with air, and the appearances are very much the same as is seen in the endothelium of other vessels. But in the arteries, if the inner surface be silver-stained before distention, the brown lines will be found to include long fusiform spaces very different from those seen enclosing endothelium elsewhere (Plate 14. fig. 25); and if the same artery be distended with air and then stained, the fine brown lines will be found to be replaced by thick and much less regular brown interspaces (Plate 14. fig. 26). There, it appears to me, the fusiform cells are elongated to their utmost and somewhat separated; and the appearances are inconsistent with my experience of vessels elsewhere lined with endothelium, and they are quite consistent with the appearances noted after the treatment of transverse sections of the umbilical arteries, distended and undistended, with vegetable-colour stains.

I have already stated that I have failed to find any trace of nerve-fibres in any part of the cord. By what mechanism, then, can this process of contraction be set going? It seems to me that the answer is readily found in three facts. First, there is no endothelium in the umbilical arteries, and the muscular fibres are therefore directly in contact with the blood which flows in them, that blood being venous as long as the placental circulation continues *. Second, it has now been well established, by Dr. Richard Norris and others, that contractility exists in muscle itself, and that nerve-influence is only its regulator, its exciter, or even its controller. Muscles depend most for their contractility on the contact of arterial blood. Thirdly, in the infant this happens to the muscular fibre of the umbilical arteries with the first few respirations. The blood in them up till that time has been venous, and suddenly becoming arterial, it throws them into violent contraction. By the cessation of the supply of arterial blood they may again dilate; for Simpson, in his collected memoirs (posthumous edition, vol. i. p. 228), says, "It is generally acknowledged by physiologists, as the result of various observations, that immediately after the child is born the umbilical vessels cease to pulsate and carry blood if the pulmonary respiration becomes active, and if the pulmonary respiration is by any cause interrupted or arrested before the cord is divided, the circulation through the umbilical vessels again becomes more or less active. Hence various practitioners have gone so far as to aver that it is unnecessary, as a general rule, to place a ligature upon the fœtal extremity of the cut umbilical cord if the cord be not cut till the child has cried loudly."

This I have repeatedly verified by experiment. By refraining from dividing the cord for a few minutes after the child is born, some very interesting observations can be made. If the child do not cry at once, and the placenta be left *in situ*, the arteries of the cord may be felt to pulsate strongly. If the child cries freely, they at once cease to beat and contract to firm threads, being felt through the flabby cord almost like cartilage. Should the child's respiration cease for a few moments they again relax and pulsate, and contract once more when the child cries. When the possibility of the circulation through the cord is arrested by the application of a ligature its stump soon ceases to give any indication of pulsation, because only arterial blood can then pass into it. The contraction and subsequent obliteration of the hypogastric arteries take place in exactly similar ways; indeed my observations were first made in these arteries and were subsequently extended to the cord.

---

* The arterialization of the blood in the capillaries, especially of the central veins of the cord, may also have much to do in exciting the contraction of the arterial coats. It may also be from this central sinus that this peculiar form of hæmorrhage occurs, which is sometimes seen after the separation of the stump.

This hæmorrhage is passive but arterial, and is seldom controlled by any ordinary hæmostatic agency. The absence of muscular walls from this sinus seems to explain some of the facts of this hæmorrhage.

The permanent closure of these vessels and of the stump of the cord is accomplished partially by clot, but chiefly by the aid of the round wandering cells previously described. They also play a very important part in what is an extremely common cause of premature death and expulsion of the fœtus. My conclusions are based upon the examination of the omphalic structures of several children who have died within thirty-six hours after birth, but chiefly on two cases of omphalic thrombosis.

It seems that immediately the arteries of the cord have contracted and the inner layers have been pressed into the folds already described (Plate 13. fig. 20), the remaining interval is filled with blood which coagulates. In the stump of a cord which had belonged to a child which lived only a few hours, I found the tissue of all the vessels permeated with the large round nucleated cells, and a few had even entered the mass of blood-corpuscles. Where the clot was not present these cells seemed to become adherent by a granular blastema to the inner surface of the wall, and to tend to arrange themselves in processes on the apices of the folds (Plate 14. fig. 22). It is doubtless through the agency of these cells mainly that the vessels are closed. I have seen complete closure without any trace of a clot: and in such a case these cells alone must effect the process. In a case where the child had lived about two days, and the cord was partly desiccated, the internal layer of muscular fibres of the arteries had in great part disappeared, leaving lacunar spaces, which were occupied by the large cells, and a complete layer of them existed between the muscular coat and the clot.

This was more and more evident as the sections neared the child. The appearances of this retrograde change (Plate 14. fig. 23) at some parts of this cord were so curious as to become almost suggestive that the muscular fibre and the nucleated canalicular tissue are developed from the same cells, that they are a mere modification of the same tissue. Some of the cells mentioned as lying in the retrograde lacunæ of the inner layer of the muscular fibres of the artery possessed the same peculiar small nucleolus as is seen in the nuclei of the canals. These cells are also seen apparently passing through amongst the outer layers of the arterial coat.

In a case where a dead child was expelled at the eighth month, clots were found to occupy the arteries from the base of the bladder to within a short distance of the cord; and in this cord (Plate 12. fig. 9) the round cells were abundant throughout the cord, and were especiall numerous in the meshes of the muscular tissues of the arteries. Roun the clot was a complete ring of these cells, apparently intimately ass ciated with it: and a few of the cells could even be seen isolated amo the blood-corpuscles, though this appearance may be due merely to the dislodgement during the process of preparation of the section (Plate 12. fig. 11).

Further proofs that these wandering cells are very efficient in the various processes of the cord and an indication of the source of their origin are obtained by the examination of the cords in cases of extra-uterine gestation. I have operated in two such cases, removing children which were quite fresh, one having been dead probably from six to ten days, and the other about three months. In both cases the cords were unaltered, save that in the second it seemed to be somewhat shrivelled. In the first case it was full and plump; but the vessels were uncontracted and unclosed, and there were no indications of any wandering cells anywhere, though the canalicular nuclei were easily displayed. The appearances in the second were somewhat similar, with the addition that the canalicular tissue was contracted, just as it becomes when the cord is examined after maceration in some hardening fluid. The canalicular nuclei were not easily shown, and appeared only here and there.

In such displacement the child seems to die of asphyxia, from the closure of some part of the canals of the mechanism by which the blood is oxygenated, and which will probably be found to occur in the placenta. The fœtal circulation ceasing, we have an arrest of the production of the wandering cells by the omphalic capillaries; and consequently they are absent from the tissue [illegible] of the cord, and there is no attempt to close the vessels.

The fact that thrombosis of the arteries occurs at least eight times more frequently than thrombosis of the vein*, and that the clots are always adherent to the walls of the arteries and more firmly than to the walls of the vein, seems also to point to this conclusion.

V. *Its Relations to the Fœtus and Placenta.*

The relations of the cord to the fœtus and placenta are very interesting. The fœtal attachment of the cord has already been described at length when speaking of the vascular supply to the canalicular tissue. In the omphalic ring nothing of the cord is found but the muscular substance of the three vessels which pass inwards, the arteries towards the pelvis, and the vein on its passage to the liver.

The canalicular tissue ends in three of the cone-like processes already described, and into which the capillaries open, either from the superficial layer or from the central sinus, or from both.

The limitation of the canalicular tissue of the cord at its placental attachment is quite as abrupt.

When the nozzle of the syringe is inserted into one of the colu the cord a short distance from the placenta and directed towar ligature being placed tightly round the cord and nozzle to prevent gitation, it will be found impossible to force the fluid into the substance of the placenta. It is limited by a membrane, derived from the inner layer of the chorion, into which the arteries pass to be included between two layers of it, and from between which two layers the veins emerge. This membrane is very tough; and if extreme pressure be used the fluid will be found to pass under the ligature and down the column which is being injected, or by rupture into one of the other columns, but never, according to my experiments, can it be made to pass through that membrane. There is absolutely no connexion, therefore, between the nutritive system of the cord and that of the placenta.

---

* Steiner's 'Kinderkrankheiten,' 1873.

The amnion is loosely attached over the placenta by some cellular tissue, which Arthur Farre describes as the *tunica media*. But the amnion becomes adherent to the cord a few lines on the fœtal side of the basis membrane of the placenta.

The relations of this attachment have yet to be made out.

VI. *Its Nutrition.*

From what I have already said it will be apparent that I regard the chief factor in the nutrition of the cord to be the capillary arrangements at its fœtal insertion, at which point the cord grows and obtains its spiral form, and from which also it derives its supply of wandering cells. From the facts observed in cases of extra-uterine gestation, however, it has seemed to me to be likely that the stomata on the epithelial surface of the cord also play an important part in its nutrition. The liquor amnii contains casein, creatin, lactic acid, grape-sugar, and some saline matter, all of which are very suggestive that the fluid is used for the purposes of nutrition, and perhaps for that of the cord. In recent cases of extra-uterine fœtation, before the liquor amnii becomes absorbed, the cord remains fresh and plump. After the liquor amnii has become absorbed it becomes shrivelled, but still retains its structural character minus the wandering cells. It may be, therefore, that the canalicular nuclei may be able to keep the cord in repair, as it were, by the matters absorbed from the liquor amnii, until that fluid disappears, very much as ivy continues to live after its connexion with the root has been severed. Indeed the resemblance between the umbilical cord and vegetable tissue is a very close one, as I have previously indicated, and as I may in future communications be able to make still more clear.

Appendix.—Received June 14, 1875.

Since the preceding note was written, I have been able completely to verify Virchow's depiction of the arrangement of capillaries on the surface of the cord, in continuity with those of the dermal ring.

The existence of this arrangement, however, must be exceptional, and is probably only an early stage of the more perfect plan already described, for I have only found it in this one case.

The fœtus in which the observation was made was a large one, but not fully developed, having probably not reached within six weeks of maturity. The injection was very successful, and was made under a pressure of only 100 millims., and the plexus of vessels was seen to extend about 5 millims. over the venous surface of the cord (Plate 13. fig. 21, *b*). But on examining the vessels with a power of thirty diameters, it is readily seen that these capillaries did not return in loops, but seemed to be lost in the substance of the cord—contrasting in this relation very markedly with the capillaries of the dermal ring, from a large trunk of which they arose. These latter are arranged in loops for the return of the circulation, as is the case with capillaries almost everywhere else; but those in the cord have an arrangement more like that of the branches of a tree. Further, it is noticeable that the capillaries spreading over the surface of the cord may be seen to arise by the aggregation of smaller roots, just as I have pointed out to be the case in the formation of the central sinus of the cord (Plate 13. fig. 21, *a*).

None of the canalicular tissue of the cord could be seen to have been injected from these capillaries; but the pressure used was too low to accomplish that, as the injection had to be made for another purpose.

The umbilical cord in this case had been cut off about 60 millims. from the dermal ring, and the injection as usual was made from the vein.

On making a section of the cord immediately below the ligature which retained the injecting nozzle, a small spot of injection was seen in the substance of the cord lying close outside the wall of the vein. This was found to be the central sinus of the cord; and on being carefully traced towards the fœtus, it was found to curve spirally close alongside the vein and to enter and pass through the omphalic canal in the midst of the three vessels.

Throughout its course, examination by a power of thirty diameters showed that it gave off branches which rapidly broke up and were lost in the tissue of the cord.

Finally, it was found to arise from several small branches, four of which at least are preserved and are represented in the drawing (Plate 13. fig. 19). They arose from the lower intercostal arteries, and gathering together on the lower surface of the omphalic vein, combined in the omphalic canal to form the sinus.

From this case it is evident that this sinus at least occasionally passes very far into the cord, as the point where it was discovered was at least 45 millims. from the dermal ring.

(I think it is possible that the radicles of this sinus may be what Kölliker described as the nerve-twigs derived from the hepatic plexus.)

EXPLANATION OF THE PLATES.

Plate 11.

Fig. 1. Median section of cord, showing the dermal ring to extend further on the cord on the upper or venous side than on the lower (actual size).
Fig. 2. Surface of cord and dermal ring, dissected off and laid flat, showing the capillaries of the former and the camb-like projection of the latter (actual size).
Fig. 3. Surface of cord, silver-stained, and epithelium partly removed (× 1000).
Fig. 4. Transverse section of cord, showing one of its three columns injected (× 120).
Fig. 5. Canalicular tissue of cord, injected (× 250).
Fig. 6. Ditto, with nuclei stained (× 200).
Fig. 7. Nuclei of canalicular tissue, highly magnified (× 1000).
Fig. 8. Ditto, with canals uninjected (× 250).

Plate 12.

Fig. 9. Round wandering cells in alveoli (×700).
Fig. 10. Round cells, highly magnified (× 1000).
Fig. 11. Ditto in neighbourhood of capillary, and some invading the blood-clot (× 1000).
Fig. 12. Two umbilical arteries, with central sinus of cord lying near them (× 20).
Fig. 13. Median section of cord and omphalic structures, with canalicular tissue (at arrow) injected on the one side of the ring, and on the other the subcutaneous tissue injected (actual size).
Fig. 14. Terminal cone of canalicular tissue, injected (× 120).

Plate 13.

Fig. 15. Central sinus of cord, with its branches and canalicular tissue injected from them (× 20).
Fig. 16. Capillary of cord, one inch from dermal ring, showing its relations to the lacunar spaces and resemblance to Haversian system (× 200).
Fig. 17. Two layers of the external coat of an umbilical artery (× 200).
Fig. 18. Diagram of the same.
Fig. 19. Drawing of roots of origin and course of central sinus of cord (by Mr. Priestley Smith, actual size).
Fig. 20. Transverse section of umbilical artery, showing rugæ (× 20).
Fig. 21. Capillaries running on to the cord from the dermal ring: *a*, showing method of origin (× 3); *b*, actual size.

Plate 14.

Fig. 22. Arrangement of wandering cells on rugæ of contracted artery for closing it (× 1000).
Fig. 23. Retrograde change in muscular coats of arteries (× 1000).
Fig. 24. Endothelium of vein, silver-stained (× 1000).
Fig. 25. Inner surface of contracted artery, silver-stained (× 500).
Fig. 26. Inner surface of distended artery, silver-stained (× 500).

Tait

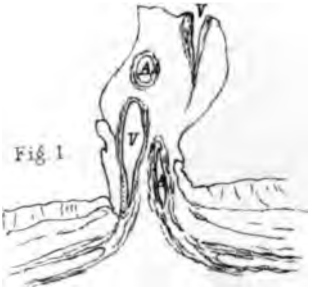
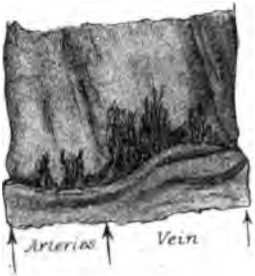
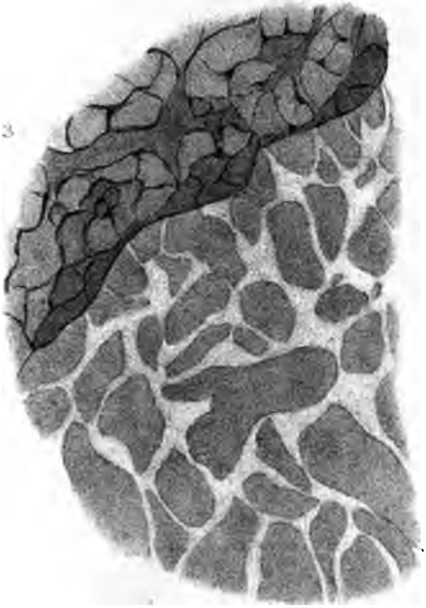
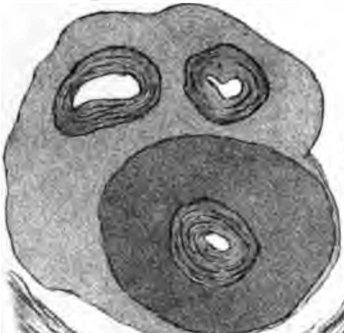
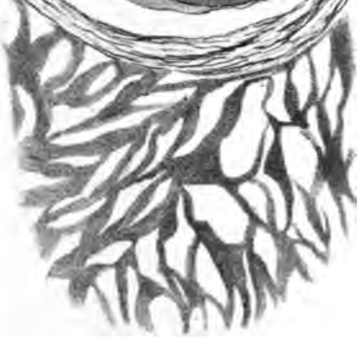


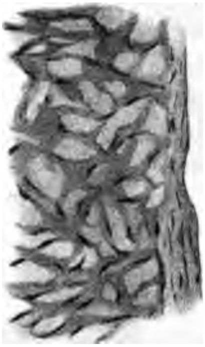
Fig. 1

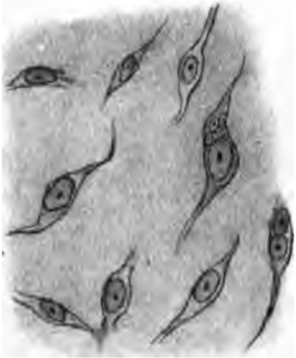

2

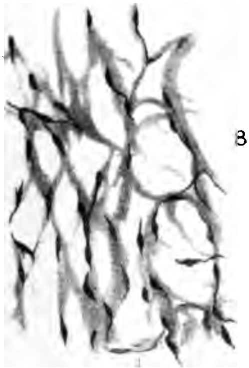

3


4.


5.


6


7.

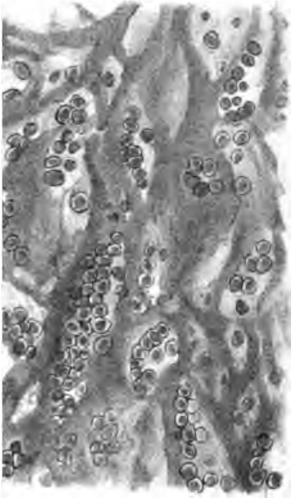

8.

L. Tait delt.

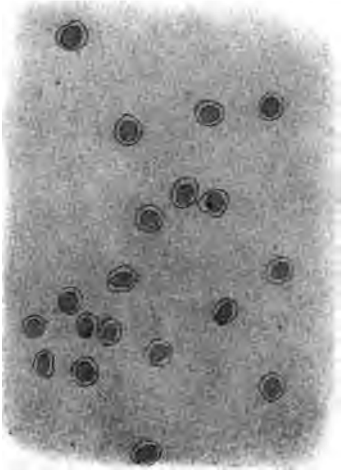
W.H. Wesley lith.

W West & C

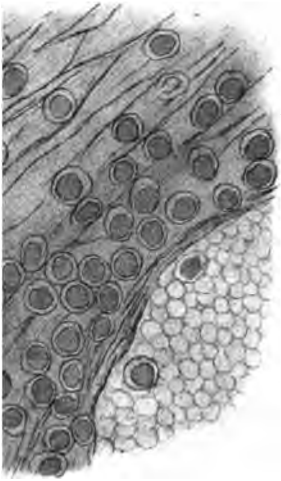
9



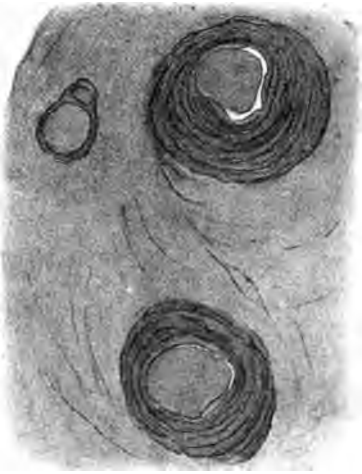
10.



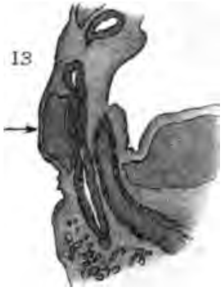
11



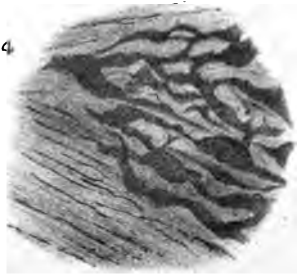
12.



13



14

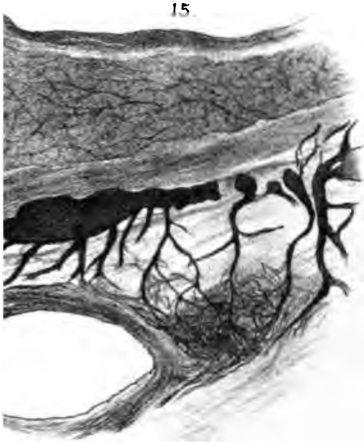


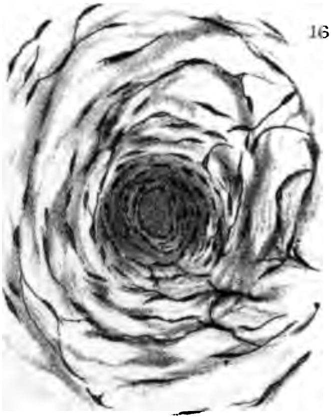
ith.

L Tait delt

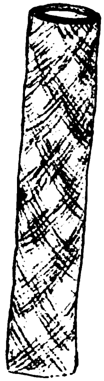
W West & Cº imp.

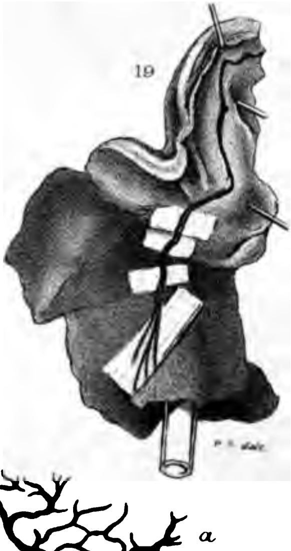
15





18.



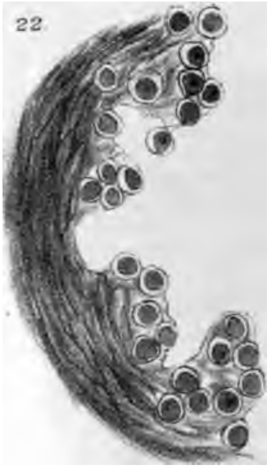


P S delt

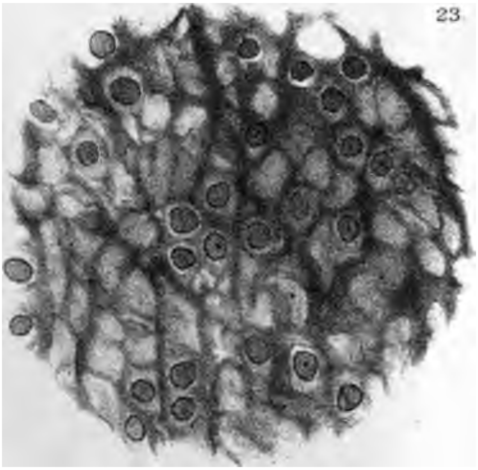
L Tait delt

W West & Co imp

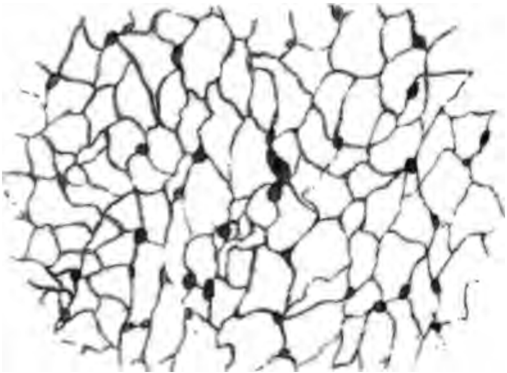
22.



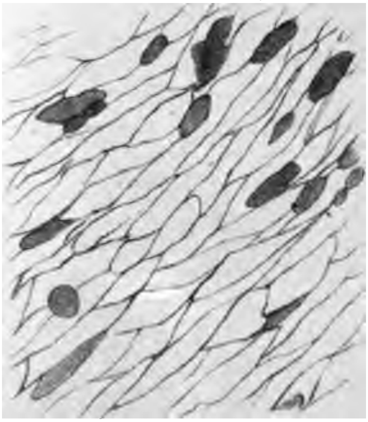
23.



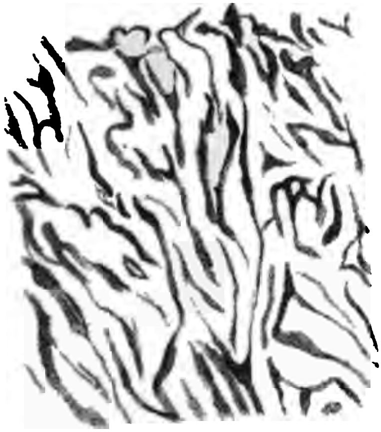
24.



25.



26.



W. H. Wesley lith.
L. Tait delt.
W. West & Co. imp.

April 6, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Experiments on the Friction between Water and Air." By Dr. Ritter von Lang. Communicated by N. Story Maskelyne, F.R.S., Keeper of the Mineral Department, British Museum. Received February 28, 1876.

(Abstract.)

The method adopted for estimating the mutual friction of water and air consisted in connecting a glass tube of 8 centims. in length and 0·72 internal diameter with the pipes which supply Vienna with water at a pressure of four atmospheres. Arrangements for securing a vertical position for the tube ensure a perfectly continuous jet, devoid of any broken surface; and a glass tube surrounding this jet, with its axis coinciding with that of the jet, acts as an aspirator into and along which air is drawn through a lateral feeding-tube. The amount of this indrawn air corresponding to the fall of a given amount of water was determined by observing the rate at which a film of soap was borne along the feeding-tube; and the velocity of the water causing the indraught was calculated from the diameter of the water column and the quantity of water discharged along it in a given time; but after having once determined the form of the slightly conical water column, the amount of water discharged was the only datum required for the calculation.

The influence of a greater or less section of the air feeding-tube on the volume of the aspirated air was carefully determined, while also the absence of any appreciable retardation due to the soap film was established.

Neglecting the slightly conical character of the surface of the water column, and assuming (as the result of experiments in which the motion of a smoke cloud was observed) that the movement of the air was throughout in lines parallel to the axis of the tube along which it flowed, and showing that the pressure does not vary along the length of the tube, the author proceeds to discuss the hydrodynamic equations expressing the conditions of the problem (the motion of the air being uniform and independent of time), and represents the volume of air A passing through the tube in a second as:—

$$A=W\left[\frac{R^2-r^2}{2r^2(\log R-\log r)}-1\right],$$

W being the weight of water, in grammes, discharged in a second, r the radius of the jet in turns of the micrometer-screw (6·8 turns of which correspond to 1 centim.), R being the radius of the aspirating tube.

The results obtained by observation accorded well with those given by this equation, so long as the value of R did not exceed the limit within which the suppositions regarding the motion of the air hold good.

The question was considered whether the results might not be brought into even closer accord with theory by the assumption that a slipping action takes place between the air and the water-jet on the one hand, and between the air and the tube on the other, instead of the assumption previously made that the air adhered alike to the water and to the tube in its passage. The result of the calculation, however, led to no nearer approximation; and, finally, experiments with other materials for the tube and other gases (namely, coal-gas and carbonic anhydride) were made, without resulting in any marked difference from the results obtained with air and glass.

II. "An Inquiry into the Cause of the slow Pulse in Jaundice."

By J. Wickham Legg, M.D., Demonstrator of Morbid Anatomy in St. Bartholomew's Hospital. Communicated by J. Burdon Sanderson, M.D., Professor of Physiology in University College, London. Received February 24th, 1876.

It has long been known to physicians that the pulse of patients jaundiced and free from fever is often slow. But I am not acquainted with any definite investigation into this subject until about thirteen years ago, when Röhrig published his researches upon the influence of the bile upon the heart*. He was the first to find out that the bile-acids, not the pigments nor the cholestearin, had the power to render the pulse slow. He formed the opinion that this slow pulse was caused by a paralysis of the cardiac ganglia, because the pulse became slow after the injection of the bile-acids into the jugular vein, even when the vagi had been cut, and because the heart of the frog, cut out and plunged into a solution of bile-acids, beat a less number of times than when cut out and immersed in serum.

The following year Traube published an altogether different explanation†. It is well known that the bile-acids have the power of dissolving the blood-corpuscles. If these bile-acids, therefore, be injected into the jugular vein, they destroy or injure the red corpuscles with which they meet, and the blood containing dissolved red corpuscles and bile-acids is quickly brought to the left side of the heart and thence into the coronary arteries. This blood is unfit for the exchange of oxygen with the muscular substance of the heart, as the red blood-corpuscles are so much injured; and it is to the consequent change in the muscular walls of the heart that Traube apparently attributes the slow pulse of jaundice.

---

* 'Arch. f. Heilkunde,' 1863, p. 385. Also in an Inaugural Dissertation, "Ueber den Einfluss der Galle auf die Herzthätigkeit," Leipzig, 1863.

† 'Berliner klinische Wochenschrift,' 1864, No. 9 and 15; also in 'Gesammelte Beiträge' (Berlin, 1871), Bd. i. p. 366.

About the same time Johannes Ranke, in the course of his researches into the phenomena of tetanus, arrived at the conclusion that the bile-acids have a paralyzing action upon the striped muscular tissue, and that it is solely by the action of these acids upon the muscular fibres of the heart that the slow pulse is caused*. He agrees with Traube in opposition to Röhrig and Landois†.

I have repeated most of the experiments of those who have gone before me; but those only will be detailed which seem to throw a new light upon the matter in hand.

The bile-acids employed in these researches were prepared from ox-gall by a slight modification of the process recommended by Kühne‡. I have to thank my friend Dr. Shuter, of Caius College, Cambridge, Assistant Demonstrator of Physiology in St. Bartholomew's Hospital, for his kindness in preparing for my use some of the bile-acids used in these experiments. In nearly all instances the bile-acids were dissolved in distilled water, 10 per cent. in strength. I should mention that the acids were not separated from their combination with soda.

My first experiments were directed altogether to the heart of the frog, which lends itself readily to researches of this kind, as it can be separated from its attachments, and its contractions kept up by being fed with serum by means of an artificial circulation. In this way I attempted to decide if the slow pulse be due to an excitement of the ends of the vagus in the heart.

The heart of a frog being arranged in Bowditch's apparatus§, the following observations were taken:—

---

* Arch. f. Anatomie u. Physiologie, 1864, p. 340; also in 'Tetanus' (Leipzig, 1865) p. 395.

† Landois, 'Deutsche Klinik,' 1863, no. 46, p. 449.

‡ Lehrbuch d. phys. Chemie (Leipzig, 1866), p. 75.

§ For a description of this apparatus see Dr. Lauder Brunton's 'Experimental Investigation of the Action of Medicines,' London, 1875, p. 72.

Time in seconds.	Pulsations.	Height of curve in millimetres.	Remarks.
In 130	31	5·5	
„	32	6	
„	38	4	Curves are double-topped.
„	31	6	Atropia introduced into serum so that it contained ·028 per cent.
30	6	7	Bile-acids (serum containing 1 per cent.) now introduced.
„	4	7	Records in continuous 30 seconds.
„	4	8	The pulse now goes in pairs, $6^{s}{\cdot}5$ between each pair of pulsations. Between the pulses of each pair $3^{s}{\cdot}2$.
„	4	8·5	These do not go in pairs.
„	4	9	
„	4	8	These go in pairs.
130	13	12	A great change in the character of curves. Systole reaches maximum height, = 6 millims., in $1^{s}{\cdot}5$. They slowly sink, scarcely meeting abscissa until next contraction begins. Nearly all alike. One takes up 23 millims., others 38 millims.
„	12·5	10	Immediately after this the heart ceases to beat: no contractions upon electrical irritation.

Four other like experiments with the like results were made: in one of them the bile-acids were added to the serum first, and the atropine added afterwards; but the same results were attained. The slowness of the pulse arose as before, and was unchanged by the addition of the atropine. If it be true, then, that atropine paralyzes the ends of the vagus in the heart, it would appear that the slow pulse is not due to any excitement of the ends of these nerves in the heart. The great height of the curves just before the heart ceased to beat does not favour, either, the belief that the slow pulse is due to a weakening of the muscular walls.

In order to test the foregoing experiments, I made further experiments upon the irritability of the vagus in poisoning by the bile-acids.

The heart and vagus of a frog laid bare. Heart beating 12 in 15^{s}. The right vagus then irritated by induced electricity: the heart stood still in diastole. Three or four drops of the pharmaceutical solution of atropine now let fall upon the heart. Five minutes after the beats were 7 in 15^{s}. The right vagus was then again irritated by induced electricity, with no change in the heart. After ten minutes, four drops of a 10-per-cent. solution of bile-acids were let fall upon the heart and neighbourhood. Thereupon, for nearly a minute, the heart-beats rose to 10 in 15^{s}, but directly after fell to 6 in 15^{s}. Five minutes after, the beats being still 6 in 15^{s}, the right vagus was again irritated, but no change followed. Three minutes after the beats were 5 in 15^{s}. Experiment was then broken off.

Two other like experiments were made and with like results. They would seem to show that the bile-acids do not restore to the vagus the inhibitory power destroyed by the atropine.

If, then, the slowness of the pulse be not due to the influence of the vagus on the heart, there remain two other factors in the movements of the heart to be considered—the ganglia and the muscular walls. Looking at the muscular walls as the cause of the slow pulse, it became of great importance to examine with care the experiments of Traube and Johannes Ranke, as to the action of the bile-acids upon striped muscular tissue. Traube himself has made no immediate observations upon muscle. He believes that the heart muscle is the organ affected, solely apparently because the low blood pressure and slow pulse so quickly disappear. I can confirm nearly all Traube's statements of fact by observations of my own. Only the ecchymoses in the conjunctiva of the side used for injection have I failed to see. The inspiratory spasm on the injection of the bile-acids into the carotid is extremely well marked, and persists after the removal of the cerebral hemispheres. But it is hard to agree with his explanation of facts, and his "muscular-motor" theory remains at present a pure hypothesis.

In repeating Ranke's experiments I followed his method of injecting 10 cubic centimetres of a 1-per-cent. solution of bile-acids in saline solution into the aorta of frogs. I noticed all the phenomena which he has described—the irregular contractions of the muscles of the limbs as the injection passed into them, their rigidity and hardness immediately after the injection, and the absence of contraction on the application of electricity to the sciatic nerves. Ranke seems to think these appearances are best explained by supposing that the bile-acids have a specific influence upon muscular tissue. Knowing, however, the power which the bile-acids possess of coagulating albumen (a 1-per-cent. solution will coagulate white of egg), it seems to me that the appearances seen would be very fully explained by the chemical action of the bile-acids upon the albuminous substances of the muscle; and a chemical action Ranke himself admits. I was thus led to make a series of experiments in which the bile-acids should not be immediately brought into contact with the muscles, but should act by means of the natural process of absorption. The bile-acid solution was injected into the lymphatic sac or under the skin of frogs. The amount given varied from ·05 to ·3 grm. Twelve experiments were made, and in nearly all no change in the curve traced by the myograph could be detected after the injection of the bile-acids, the observations lasting up to the time that the muscles responded to any amount of electricity that I was able to bring to bear upon them.

The method used was as follows: the sciatic nerve was prepared, carefully avoiding all injury of blood-vessels; the tendon of the gastrocnemius was attached to a string, and separated from the heel. The frog was then put into a moist chamber, and the string attached to the tendo Achillis fastened to a telegraph lever writing on a revolving cylinder. The sciatic nerve was then irritated by means of electricity from a Du-Bois-Reymond's coil; it was applied not oftener than once every 60^s, and only of such amount as to cause the muscle to contract.

I here extract from my experiment-book a few experiments detailed at length.

Jan. 22.—Excellent normal curves obtained. ·1 grm. of bile-acids injected under skin of back: no change in the curves, save that they grow smaller in height from 15^m to 60^m after the injection.

Feb. 2.—·3 grm. of bile-acids injected into the lymph-sac of frog: no change from normal curves from 16^m to 92^m after the injection.

In three of these experiments changes in the natural curve were noticed after the injection of the bile-acids. The same appearance was seen in all three, namely, that the muscle was a long time in recovering itself. The down stroke of the muscle curve took some space before it reached the abscissa. In two of these cases, however, the muscle curves taken before the injection of the bile-acids showed the same appearance. After the injection the prolongation of the curve became somewhat more marked, varied by returns to almost normal markings. It is thus impossible to attribute any weight to these variations. The amount of bile-acid given in these two cases was ·2 and ·3 grm. respectively. In the third case in which this lengthening of the curve was noticed no markings were taken before the injection, so that from this case it is again impossible to draw any inference. The amount of bile-acid given was ·3 grm.

If, then, the bile-acids have no physiological action upon striped muscular tissue, have they yet any chemical influence upon the ventricle alone? I thought, therefore, of making some experiments upon the action of the bile-acids on the ventricle when separated from the rest of the heart. It is commonly said that the ventricle of the frog's heart continues to beat for some time after it be severed from the auricles. I found, however, that the time was not long enough, nor the beating of the ventricle constant enough, to enable me to judge of the difference in time taken to bring the ventricle to a standstill if immersed in serum, or in serum containing 1 per cent. of bile-acids. I therefore fell back upon a method lately employed by Luciani*. It consists in introducing into the ventricle of the frog's heart a tube divided vertically by a septum, and tying the ventricle on to the cannula below the auricles. The heart is supplied by serum through the double cannula, and each pulsation is recorded by a manometer[*]. I made five of these experiments, but could detect no change in the alternate standstill and tetanus, described by Luciani, after the introduction of bile-acids in 1 per cent. into the serum, nor after the removal of the bile-acid serum and the feeding of the heart with pure serum. Both before and after the use of the bile-acids the contractions of the ventricle were the same. It would seem, therefore, that the bile-acids have no influence, either chemical or physiological, upon the ventricle of the frog's heart separated from the auricles.

---

* Arbeiten aus d. phys. Anstalt zu Leipzig, Jahrg. vii. 1873, p. 120.

If, then, the bile-acids have no influence upon the ends of the vagus in the heart, nor upon the muscular tissue, there remains, in the present state of knowledge, only one other cause of the heart's movement which may beget a slow pulse, viz. the ganglia of the heart. Arguing, therefore, *per viam exclusionis*, the same conclusion is reached as that of Röhrig, viz. that it is the action of the bile-acids upon the ganglia of the heart which causes the slow pulse in jaundice. The same conclusion is come to, but upon altogether different grounds; for it must be acknowledged that the grounds upon which Röhrig formed his opinion seem, in the present state of physiology, to be insufficient.

I have also made some experiments upon the influence which the bile-acids have upon the rate of pulsation of the lymphatic hearts of frogs. The rate does not seem to be in any way influenced by the bile-acids. The heart only begins to beat more slowly where general death is setting in from the action of the poison. The blood-heart, on the contrary, begins to feel the influence of the poison within a few minutes of its injection, and the pulsations may sink from 13 to 3 in 15^{s} in seven minutes after the injection of 1 cubic centimetre of the bile-acid solution under the skin.

I have made six observations upon the lymph-hearts, of which I add the details of one.

Dec. 24th.—Right posterior lymphatic heart exposed at 10.55 A.M. The pulsations vary from 7 to 9 in 15^{s}. At 11.5 the average is 9 in 15^{s}. At 11.7 one cubic centimetre of bile-acid solution was injected under the skin of the neck.

At 11.12 A.M. 10 in 15^{s}.
11.15 „ 9 „
11.20 „ 9 „
11.24 „ struggles.
11.28 „ 9.
12 noon 10 in 15^{s}.

At 12.20 P.M. another injection.
12.25 „ 11 in 15^{s}.
12.31 „ 10 in 16^{s}.
12.35. Lymph-hearts now ceased to act.
2.0 P.M. Animal found dead.

I have likewise made some observations upon the changes in the reflex movements which follow the administration of the bile-acids. I choose one of five experiments nearly all alike.

---

[*] The double cannula is called by the Germans *Froschherzventrikelbestimmungs-apparat*, and may be had of Hornn, the instrument-maker in Leipzig. The one sent by him to me was, however, too large for the hearts of English frogs, and a smaller one on the same plan was made for me by Hawksley, of Oxford Street.

Dec. 19*th*.—The anterior cerebral hemispheres of a frog, leaving the optic thalami uninjured, removed. The foot was irritated by being plunged in water made just perceptibly acid to taste by sulphuric acid. The numbers are in seconds.

12.22. 12, 6, 7, 8, 6, 7, 6.

12.32. ·5 cubic centimetre of bile-acid solution injected under the skin of the back.

12.39. 1, 2, 1, 1, 29, 27, 15, 16, 21, 28, 22, 26.

The head cut off at 1 o'clock.

1.25. 9, 9, 9, 9, 10, 10, 10.

In all cases a minute passed between the application of the irritant, and the foot was well washed with distilled water after each observation.

From these observations it would appear that the reflex irritability is greatly diminished by the bile-acids.

In conclusion I wish to express my best thanks to Professor Burdon Sanderson, F.R.S., and to Dr. Lauder Brunton, F.R.S., for their great kindness in giving me invaluable advice and assistance throughout the research. Many of the experiments were made in the Jodrell Laboratory at University College, London, under Professor Burdon Sanderson's eye; and the remainder were made in the Pharmacological Laboratory of my friend and colleague Dr. Lauder Brunton, at St. Bartholomew's Hospital.

III. "On the Structure of a Species of *Millepora* occurring at Tahiti, Society Islands." By H. N. Moseley, Naturalist to the 'Challenger' Expedition. Communicated by Prof. Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff. Received March 6, 1876.

(Abstract.)

In a paper treating mainly of the structure of *Heliopora cærulea*, communicated to the Royal Society in the autumn of 1875, some account was given of results arrived at from the examination of two species of *Millepora* obtained at Bermuda and at Zamboangan, Philippines; and in that paper a summary of the literature concerning the tabulate corals generally was given. The present paper, to be considered to a certain extent a continuation of the last, gives an account of the structure of a species of *Millepora* obtained at Tahiti, Society Islands. The author commences by expressing his obligations to his colleague Mr. J. Murray, who obtained living specimens of the *Millepora* and handed them over to him with the zooids in the expanded condition for examination, and who further, having devoted some time to the study of the coral, gave him valuable information with regard to several points in its structure.

No *Millepora* appears to have been hitherto known to occur at Tahiti. The name of the species of the one the structure of which is described in the paper was not ascertained. It resembles *M. tuberculosa*, as described by Milne-Edwards [*], in outward form, but differs from it in having the calicles of two kinds disposed on the surface of the corallum in regular separate systems, in this respect resembling more closely *M. plicata*, *M. foliata*, and *M. Ehrenbergii* as described by the same author.

The coral was examined in the fresh condition, and also preserved in alcohol, chromic acid, and glycerine, and treated with osmic acid. Hardened specimens were decalcified and examined by means of sections. The corallum is a spongy mass composed of more or less contorted trabeculæ of calcareous matter, which is disposed in a series of thin layers following the contours of the surface, and representing successive additions by growth. Within these layers ramify a series of canals which give off branches and subbranches, the whole ramifications being intimately connected with one another, and with the calicular cavities, by a network of smaller channels. The main canals are sometimes large enough to be easily seen by the naked eye, and run for as great a distance on the surface of the corallum as 1½ inch. This system of branching canals is held to be characteristic of the coralla formed by the hydroid genus *Millepora*, distinguishing it from all other coralla. The calicles are of two kinds, small and large. They are disposed on the surface of the corallum in irregularly circular systems. A large calicle occupies the centre of each system, and is surrounded by a ring of smaller calicles, usually from five to eight in number. In histological structure, as also in chemical composition [†], the coralla of the genus *Millepora* seem to show no marked differences from Anthozoan coralla.

The zooids are of two kinds. The one, short and stout, occupies the larger central calicles of the systems, has from four to six short knobbed tentacles, and is provided with a mouth and certain gastric cells, closely resembling those figured by Allman as occurring in *Gemmaria implexa* [‡]. The other kind occupies the smaller calicles, is longer and more slender than the mouthed zooid, has from five to twenty tentacles, and no trace of a mouth. The usual number of tentacles in the mouthless zooid is about twelve to fifteen. The tentacles are larger than in the mouthed zooid, and disposed at irregular intervals along the body. They show the transverse striation, or apparent septa, so characteristic of the tentacles of hydroids. They have spheroidal heads composed of masses of thread-cells.

The zooids of both kinds are provided with well-marked longitudinal muscular fibres, which are disposed in bundles, and are attached inferiorly to the vessels of the hydrophyton which join the somatic cavity at the base of the zooids. Circular muscular fibres are possibly also present. As in *Heliopora*, only a thin layer at the surface of the coral is living.

---

[*] Hist. Nat. des Coralliaires, pl. F 3. figs. 1*a*, 1*b*.

[†] Structure and Classification of Zoophytes, by J. D. Dana (Philadelphia, 1846), Appendix, p. 130. Corals and Coral Islands, *ejusd.* (London, 1872), p. 105.

[‡] Gymnoblastic and Tubularian Hydroids, pl. viii. fig. 5.

The soft parts of the hydrophyton consist of a network of canals and vessels occupying the corresponding canals in the corallum. The canals are composed of an ectoderm and endoderm. The ectoderm rests on a thin layer of membrane. It is mainly composed of fusiform fine granular cells with an oval nucleus, but is much modified in certain regions. In the upper part of the living layer its cells are abundantly converted into the parent cells of thread-cells, and on the actual surface into a layer of prismatic cells showing at the very surface hexagonal outlines. This layer is believed to be continuous over the whole outer surface of the coral. It is continued down into the calicular cavities, and in the contracted condition almost closes their orifices. The endoderm consists of two elements—yellow pigmented cells closely similar to those of other hydroids, and small transparent highly refracting globules. The pigmented cells are abundant in the somatic cavities of the zooids, and in the canals and vessels of the hydrophyton. They impart a bright yellow colour to the tips of the tubercles of the living coral. The canal-system of the hydrophyton anastomoses most freely with the somatic cavities of the zooids, and establishes a free communication between them. Two kinds of thread-cells are present. The one is of the peculiar form occurring only in Hydrozoa, viz. that which has in the expanded condition a short, wide, bladder-like structure at the base of the thread next the cell, which bladder is armed with three spines set in one whorl. In *Millepora* the spines are unusually long and set at right angles to the thread. This kind of thread-cell alone occurs in the tentacles; it occurs also more sparingly in the hydrophyton.

The other kind of thread-cell is larger and ovoidal in form, closely resembling that figured by Allman as occurring in *Gemmaria implexa*. These thread-cells are confined to the hydrophyton. They form densely set zones around the bases of the zooids.

The other species of *Millepora* examined appear to agree in all essential particulars with that occurring at Tahiti. They have mouthed and mouthless zooids, but these are not arranged in regular systems. They have the same two kinds of thread-cells, with a similar distribution. The Tahitian *Millepora*, like the others examined, is infested by a parasitic fungus, which exists in the soft superficial tissues, as well as in the substance of the corallum, and has a decided green tint.

IV. Supplemental Note to a Paper* "On the Structure, Physiology, and Development of *Antedon* (*Comatula*, Lamk.) *rosaceus.*" By WILLIAM B. CARPENTER, M.D., F.R.S. Received April 6, 1876.

Since my communication of the above-cited Paper to the Royal Society on the 16th December, 1875, two important contributions to the Anatomy of *Antedon* have appeared—one by Dr. Ludwig, chiefly based on his study of *Antedon Eschrichtii* ("Zur Anatomie der Crinoiden," Zeitschrift für Wissenschaftliche Zoologie, Bd. xxvi. 1876, p. 361, continued in Nachrichten von der Königl. Gesellschaft der Wissenschaften und der G. A. Universität zu Göttingen, No. 5, Feb. 23, 1876), and the other by Prof. Greef, of Marburg (Sitzungsberichte der Gesellschaft zur Beförderung der gesammten Naturwissenschaften zu Marburg, January 1876), both of which seem to have been prompted by the appearance of Professor Semper's short paper on the subject. These able observers fully concur with me, as to all essential particulars, in the account I have given of the triple canal-system of the arms, which M. Edmund Perrier not only could not himself find, but ventured to predict that no one else would find; in fact, Professor Greef's figure of a transverse section of an arm might have been copied from one of the drawings I have had by me for more than ten years, save for one slight additional feature. The German investigators also accept the correctness of the statements made by me in my First Memoir, that the "nerve" of Müller is really the genital rachis, and that Müller's "vessel" in the arms is solid, not tubular, though neither is disposed to believe with me that this "axial cord" is a nerve. The character of a nerve, on the other hand, is assigned by Ludwig to a fibrillar band lying beneath the epithelial floor of the ventral furrow of the arms; which band had been independently noticed by my son, Mr. P. H. Carpenter † (who is at present working in the laboratory of Professor Semper at Würzburg), in two of Professor Semper's Philippine species, *Actinometra armata* and *A. nigra*, as also in *Antedon Eschrichtii*, in which it had been previously discovered by Ludwig. It is not nearly so distinct, however, in *A. rosaceus*; but its existence in that species was also independently recognized by Professor Huxley, who, like Ludwig, was led by his general view of the homologies of the Crinoids to regard it as a nerve. My son regards both the ventral band of Ludwig and my "axial cord" as belonging to the nervous system, being led to that conclusion, as regards the former, by its homology with the radial nerves of other Echinoderms, and, as regards the latter, by the very definite branching he has discovered in the axial cord of the arms of *Actinometra armata* and *A. nigra*—two pairs of branches running on each side towards the dorsal surface, and two towards the ventral, where he has distinctly traced their ramifications as far as the leaflets bounding the ventral furrow. Prof. Greef, on the other hand, describes the whole epithelial floor of the ventral furrow as a nerve, on the ground that its histological character resembles that of the nerves of other Echinoderms.

---

* See *antè*, p. 211.

† "Remarks on the Anatomy of the Arms of the Crinoids," in the Journal of Anatomy and Physiology for April, 1876, p. 571.

Having recently had an opportunity of examining at Würzburg the very thin sections prepared by my son, I can say with certainty that the fibrillar band is quite distinct from the layer of columnar epithelium which it underlies; but it appeared to me to send off very minute fibrils that pass up between the cells of which that layer is composed.

To myself it appears by no means improbable, looking alike to its position and to its histological characters, that this band is a nerve; but having regard to its immediate proximity to the sensory (ventral) surface, and to its separation from the muscles by the interposition of the triple canal-system, I cannot but think it more likely that it is functionally related rather to the former than to the latter—in other words, that it is an *afferent* rather than a *motor* nerve.

As it seemed to me that important evidence might be obtained on this point from experiments made on the living animal, I took the opportunity afforded by my recent visit to the Zoological Station at Naples to institute such experiments; the results of which I am desirous of appending to my Paper, as they seem to me to place the doctrine advocated in it beyond reasonable doubt.

Every one who has had the opportunity of observing the habits of the living *Antedon* well knows the peculiarly rhythmical and symmetrical swimming action which it executes when it spontaneously leaves or is detached from the anchorage afforded by the grasp of its dorsal cirrhi. Each of its five rays divaricates into two arms, which may be characterized (like the two legs proceeding from the human trunk) as the *right* and the *left* respectively; and the act of swimming consists in the alternate consentaneous advancement of the *five right* and then of the *five left* arms, each of which is bent forwards in a curve which resembles that of the swan's neck in its graceful arch, and is then straightened backwards. The perfect similarity of the movements of all the five arms that work together, involving the conjoint contraction of several hundred pairs of muscles, seems to me to point almost certainly to coordination through a nervous centre; and it will be seen that experiment has fully confirmed that conclusion.

It will be recollected that the centre of what I regard as the motor nervous system is the quinquelocular organ contained in the centro-dorsal basin, which Müller (who did not recognize its cavitary subdivision) characterized as a heart. Müller's view of its nature is still upheld by Greef (*loc. cit.*), who says that it gives off vessels to the cirrhi, and regards what I have described as a circular commissure (analogous to the "circle of Willis") as a closed blood-vascular system in connexion with this, although he admits that the axial cords of the arms, which are derived from this ring, are solid. The careful and repeated investigations I have made on this point, however, have fully satisfied me that my previous statement was correct. There is no passage whatever out of the chambers into the axial cords either of the cirrhi or the rays; and in the pedunculate Crinoids, as in the early Pentacrinoid stage of *Antedon*, there is no ventricular dilatation, the solid radial cords directly arising from the axis.

Experiment 1.—Taking up a large and vigorous specimen of *Antedon*, I turned the entire visceral mass out of the calyx, leaving behind it, therefore, as the *centrum* of the animal, only the calcareous segments of the calyx with their muscles and ligaments, the centro-dorsal basin with its cirrhi, and the five-chambered organ contained in the cavity of that basin. On replacing the animal in the water, *it executed the usual swimming movement as perfectly as the entire animal had previously done.*

Experiment 2.—I removed from a second specimen, which I took out of the water in the act of swimming, the entire centro-dorsal basin, with its contents and appendages, leaving every other part as it was. On replacing the animal in the water, *all the arms were rigidly straightened out*, apparently by the action of the elastic ligaments, which the muscles were powerless to antagonize.

This second experiment, then, not only confirmed my previous belief that the source of the perfect coordination of the swimming movements lies in a Nervous centre, but seemed to establish beyond doubt that the quinquelocular organ is the instrument of that coordination—the centre of a Nervous system, whose peripheral portion consists of the axial cords of the rays, arms, and pinnules. On the other hand, the first experiment, taken in connexion with the second, clearly shows that nothing contained in the Visceral mass is essential to the perfect coordination of the swimming movements. And since it is clearly in the oral ring that we should expect to find the centre of any nervous system lying immediately beneath the tentacular furrow, it seems to me fair to conclude that the supposed "nerve" of Ludwig, if a nerve at all, has no immediate relation to those movements.

Experiment 3.—I divided, in another lively specimen of *Antedon*, the soft parts of one of the arms down to the calcareous segment, thereby cutting through the "nerve" of Ludwig. This ought, on his supposition, to paralyze the arm so treated, or at any rate to destroy the consentaneousness between its movements and those of the other arms. But on replacing the specimen in water, *all the arms worked as usual*, without the slightest disturbance of regularity.

Experiment 4.—I then endeavoured to make a corresponding section of *my* nerve, the "axial cord," by cutting from the dorsal side of the arm, with the blade of a very thin knife, sufficiently deep between the segments to divide that cord without injuring the "nerve" of Ludwig. Having been repeatedly baffled in this endeavour, however, by the throwing-off of the half-divided arm, I had recourse to another method, the application of nitric acid. Carefully drying with a bit of blotting-paper the part to be thus burned away, so as to prevent the spreading of the acid, I applied it with a finely pointed camel-hair pencil, until I had reason to feel sure that it must have reached the axial canal. On replacing the animal in the water, *that arm remained rigidly stretched out, while all the other arms worked as usual.*

Now if these experiments, taken in connexion with the one described in my Paper, which I have again repeated with the same result, are not admitted as valid evidence that the quinquelocular organ with its radiating cords constitute a Nervous system, I am at a loss to understand what is the superior probative force of the evidence which is universally held to justify the assignment of such functions to the Brain, Spinal Cord, and the white solid cords proceeding from these centres in a Vertebrate animal. And I should feel it necessary to enter a strong protest against the refusal of a similar character to what I hold to be the Nervous system of the *Crinoida* (if based on no other objection than that its position does not correspond with that of the accredited Nervous system of other Echinodermata), were it not that an investigation which I commenced seven years ago into the structure of the *Ophiurida* showed that they will probably afford the means of bridging over this difficulty; for the calcareous segments of their arms, instead of being perforated by a central canal, have a deep notch on their ventral margin, which is sometimes almost completed into a canal; so that there is here an easy passage on the one hand towards the *ventral* nerve-cord of the *Asteroida*, on the other towards the *central* nerve-cord of the *Crinoida*. Further, it is to be borne in mind that in the early stage of the development of the Pentacrinoid larva of *Antedon*, as described in the First Part of my Memoir (Phil. Trans. 1855), the "axial cords" lie on the *ventral surface* of the Radials and Brachials, which are then mere flat plates; by an endogenous thickening of the calcareous network of those plates, the axial cords come to lie in *furrows* channelled out in their ventral surfaces; while by a further endogenous growth of that network these ventral furrows are completed into *canals*; and it is by a still further endogenous thickening that these canals finally come to occupy the *centre* of each Radial and Brachial calcareous segment.

At the same time I would repeat that I see no reason for refusing to believe that the subepithelial band of Ludwig is a sensory nerve, the functions of the single trunk of the *Asteroida* being here divided between two, an afferent and a motor, just as, in Man, the double function of an ordinary spinal nerve is divided in the head between the 5th and 7th pairs. And it seems not unlikely that while the "axial cords" (motor nerves) of the arms are derived from the peripheral part of the Crinoidal axis, the "ventral bands" (sensory nerves) are derived from the central part of that axis, which has been shown to be continued, as the "axial prolongation," to the oral ring.

The Society then adjourned over the Easter Recess, to Thursday, April 27, 1876.

April 27, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

THE BAKERIAN LECTURE, "On the Gaseous State of Matter," was delivered by Prof. T. ANDREWS, LL.D., F.R.S., Vice-President of Queen's College, Belfast. The following is an Abstract:—

After referring to certain modifications in his former method of working at high pressures, the author describes some preliminary experiments which were undertaken to determine the change of capacity in the capillary bore of the glass tubes under the pressures employed. From these experiments it appears that, on raising the pressure from 5 to 110 atmospheres, the capacity was increased for each atmosphere by only 0·0000036, and that this change of capacity was chiefly due to compression of the internal walls of the glass tube. Another set of experiments was made to ascertain whether air or carbonic-acid gas is absorbed at high pressures to any appreciable extent by mercury. For the method of operating and other details reference must be made to the original memoir; but the general result is that no absorption whatever takes place, even at pressures of 50 or 100 atmospheres. The pressures are given according to the indications of the air-manometer in the absence of sufficient data (which the author hopes will be soon supplied) for reducing them to true pressures. In the mean time it is probable, from the experiments of Cailletet, that the indications of the air-manometer are almost exact at 200 atmospheres, and for lower pressures do not in any case deviate more than $\frac{1}{80}$ from the true amount.

In a note which was published last year in the 'Proceedings' of the Society (No. 163), it was stated that the coefficient of expansion (α) for heat *under constant pressure* changes in value both with the pressure and with the temperature. The experiments on this subject are now completed, and are described at length in this paper. The final results will be found in the two following Tables. In the first Table the values of α are referred to a unit volume at 0° and under one atmosphere. In the first column the pressure p in atmospheres is in terms of the air-manometer.

p.	α (0°–7°·5).	α (0°–64°).	α (64°–100°).
17·09	......	0·005136	0·004747
20·10	0·00607	0·005533	0·004958
22·26	......	0·005811	0·005223
24·81	0·00700	0·006204	0·005435
27·69	0·00782	0·006737	0·005730
31·06	0·00895	0·007429	0·006169
34·49	0·01097	0·008450	0·006574

For higher pressures than 35 atmospheres a different unit volume must be taken, on account of the liquefaction of the carbonic acid. The next Table contains the values of α, *referred to the unit volume at* 64°, between 64° and 100° at constant pressures up to 223 atmospheres.

p.	α (64°–100°).	p.	α (64°–100°).
17·09	0·003572	46·54	0·004946
20·10	0·003657	54·33	0·005535
22·26	0·003808	64·96	0·006512
24·81	0·003892	81·11	0·008033
27·69	0·004008	106·90	0·013150
31·06	0·004187	145·50	0·018222
34·49	0·004266	223·00	0·008402
40·54	0·004596		

As the value of α changes with the temperatures, the coefficients given above are average coefficients for the ranges of temperature specified. It will be observed that the value of α increases with the pressure until a very high pressure is attained, when it changes its direction and diminishes. This apparent anomaly depends upon the carbonic acid at the high pressure having passed from the gaseous state proper to the intermediate conditions, which the author has formerly described as establishing a continuity between the gaseous and liquid states of matter.

If we designate by α' the coefficient of elastic force when a gas is heated under a constant volume, we shall have in the case of a perfect (ideal) gas

$$\alpha=\alpha'.$$

In the ordinary gaseous state the value of α' diverges widely at high pressures from that of α, as will appear from the two following Tables. In the first Table the values of α' are referred to a unit pressure at 0°, and p is the initial pressure in atmospheres.

p.	α' (0°–6°·5).	α' (0°–64°).	α' (64°–100°).
16·42	......	0·004754	0·004607
21·48	0·00537	0·005237	0·004966
25·87	0·00588	0·005728	0·005406
30·37	......	0·006357	0·005861
33·53	0·00734	0·006973	0·006334

In the next Table the value of α' between 64° and 100° referred to a unit pressure at 64° is given for a large range of pressure. Both the initial and final pressures are given.

p.	α' (64°–100°).	p.	α (64°–100°).
21·42	0·003526	48·40	0·004387
24·19		56·16	
28·65	0·003718	67·65	0·005392
32·60		80·99	
35·29	0·003956	94·27	0·007018
40·44		118·60	
42·74	0·004166		
49·25			

As the general result of this investigation, it follows that in the ordinary gaseous state the law of Gay-Lussac does not hold good, either in the case of α or of α', and that the dilatation *by heat of a body in the ordinary gaseous state, whether measured by its expansion under constant pressure or by the increase of elastic force under constant volume, is not a simple function of the initial volume or initial elastic force, but a complex function changing with the temperature.*

In the second part of the paper the general properties of the ordinary gaseous state are considered. As the basis of this inquiry, the following Table of the compressibility of carbonic acid at 6°·5, 64°, and 100° is given, in which ϵ is the ratio of the observed volume of the carbonic acid at the pressure p and temperature t' to its volume under one atmosphere at the same temperature t'.

p.	$t'=6^\circ\cdot5$, ϵ.	p.	$t'=64^\circ$, ϵ.	p.	$t'=100^\circ$, ϵ.
12·01	$\frac{1}{12\cdot95}$	17·60	$\frac{1}{18\cdot57}$	20·17	$\frac{1}{20\cdot98}$
13·22	$\frac{1}{14\cdot37}$	20·36	$\frac{1}{21\cdot65}$	22·37	$\frac{1}{23\cdot35}$
14·68	$\frac{1}{16\cdot13}$	22·56	$\frac{1}{24\cdot18}$	24·85	$\frac{1}{26\cdot09}$
17·09	$\frac{1}{19\cdot12}$	25·06	$\frac{1}{27\cdot08}$	27·76	$\frac{1}{29\cdot32}$
20·10	$\frac{1}{23\cdot03}$	28·07	$\frac{1}{30\cdot64}$	31·06	$\frac{1}{33\cdot05}$
22·26	$\frac{1}{25\cdot96}$	31·39	$\frac{1}{34\cdot67}$	34·57	$\frac{1}{37\cdot03}$
24·81	$\frac{1}{29\cdot62}$	34·92	$\frac{1}{39\cdot08}$	40·09	$\frac{1}{43\cdot54}$
27·69	$\frac{1}{34\cdot03}$	40·54	$\frac{1}{46\cdot34}$	45·99	$\frac{1}{50\cdot63}$
31·06	$\frac{1}{39\cdot59}$	46·56	$\frac{1}{54\cdot57}$	53·81	$\frac{1}{60\cdot30}$
34·49	$\frac{1}{45\cdot80}$	54·33	$\frac{1}{65\cdot97}$	64·27	$\frac{1}{73\cdot97}$
		64·96	$\frac{1}{83\cdot44}$	80·25	$\frac{1}{96\cdot65}$
		81·11	$\frac{1}{114\cdot0}$	105·69	$\frac{1}{137\cdot6}$
		106·88	$\frac{1}{185\cdot5}$	145·44	$\frac{1}{218\cdot0}$
		145·54	$\frac{1}{325\cdot9}$	223·57	$\frac{1}{379\cdot3}$
		222·92	$\frac{1}{446\cdot4}$		

If we put $\rho=\epsilon p$, and calculate the values of ρ for each of the above experiments, it will be found that these values diminish regularly as the pressure increases at each temperature, with the exception of the last observation at 64°, where the value of ρ is greater than at the preceding observation. This change of direction in the value of ρ is explained by the circumstance already mentioned, that the carbonic acid at the higher pressure has been reduced to the liquid volume (although no liquefaction has taken place) in passing through the conditions of matter intermediate between the gaseous and liquid states.

The relations between the volumetric curves in the ordinary gaseous state for different temperatures are determined by means of what the author calls the homologues or homologous points of those curves—that is, the points in any two isothermals where the values of ρ are equal, or

$$p\,v=p'\,v'. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$$

From a careful analysis of the experiments described in this communication and in his former Bakerian Lecture, the author shows that the ordinary gaseous state is characterized by the ratio of the external pressures for all the homologues of any two given temperatures being constant, or

$$\frac{p}{p'}=\mathfrak{m}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (B)$$

where $\mathfrak{m}$ is a constant. It must be carefully observed that v and v' in equation (A) are the volumes of the gas on different isothermals.

It follows from these results that, in the case of a body in the ordinary gaseous state, if the relations of pressure and volume are known at any one temperature, the corresponding relations at any other temperature can be calculated from the observation of a single homologue at the second temperature. Thus the whole relations of volume and pressure will be known from a set of primary observations at a fixed temperature and the determination of one homologue for each of the other temperatures.

The general form of the primary curve itself, or curve exhibiting the relations of pressure and volume at a given temperature, is next investigated; and the author finds, as the result of all his experiments under very varied conditions of temperature and pressure, that the value of $\epsilon(1-\rho)$ is constant for the same temperature. Hence we have for the third equation of the ordinary gaseous state

$$v(1-pv)=c\,.\,.\quad\ldots\ldots\ldots\ldots\quad(\mathrm{C})$$

From this last equation the relations of homologous points, as defined by equations (A) and (B), may be deduced.

The author concludes with some general observations on the action of the internal attractive forces in the ordinary gaseous state, and also on the resistance to diminution of volume which, under certain conditions, modifies largely the effects both of external pressure and of internal attraction.

Presents received, April 6, 1876.

Transactions.

Angers:—Société Industrielle et Agricole. Bulletin. 46^e^ année. 1^er^ trimestre. 8vo. 1875. The Society.

Cherbourg:—Société Nationale Académique. Mémoires. 8vo. 1875. The Society.

Lund:—Universitet. Ars-skrift (Acta). Tome XI. 1874. Mathematik och Naturvetenskap. 4to. 1874–75. Biblioteks Accessions Katalog, 1872, '73, '74. 8vo. 1873–75. The University.

Montreal:—Natural-History Society. The Canadian Naturalist and Quarterly Journal of Science. New Series. Vol. VII. No. 7, 8; Vol. VIII. No. 1. 8vo. 1875. The Society.

Perpignan:—Société Agricole, Scientifique et Littéraire des Pyrénées Orientales [Mémoires]. Vol. XVIII., XXI. 8vo. 1871–74. The Society.

Rome:—Accademia Pontificia de' Nuovi Lincei. Atti. Anno 28. Sess. 7; Anno 29. Sess. 1, 2. 4to. *Roma* 1875–76. The Academy.

Transactions (*continued*).

Rome:—R. Accademia dei Lincei. Anno 271, 272. Serie 2. Vol. I., II. 4to. *Roma* 1875. The Academy.

Reports &c.

Wellington:—Geological Survey of New Zealand. First General Report on the Coal Deposits of New Zealand, by Dr. Hector. 8vo. 1866. Abstract Reports on the Progress of the Survey, 1866–67, 1868–69. 8vo. Colonial Museum Report, 1866–67. 8vo. Third and Fourth Annual Reports of the Colonial Museum and Laboratory. 8vo. 1868–69. Catalogue of the Colonial Museum. 12mo. 1870. New Zealand Exhibition. 1865. Reports and Awards of the Jurors. 8vo. *Dunedin* 1866. Descriptive Catalogue of the Exhibits in the New Zealand Court of the Vienna Exhibition. 1873. 4to. Official Handbook of New Zealand, edited by Sir Julius Vogel. 8vo. 1875. Classified Catalogue of the Library of the General Assembly of New Zealand. 8vo. 1875. Wise's Directory of New Zealand for 1875–76. 4to. 1875. Statistics of the Colony of New Zealand for 1874. folio. Results of a Census of New Zealand, 1871. folio. 1872. Results of a Census, 1874. folio. 1875. Dr. Hector, F.R.S.

Statistics of the Colony of New Zealand for 1873, 1874. folio. Results of a Census of New Zealand, 1874. folio. 1875. The Registrar-General of New Zealand.

M'Lachlan (R.) Monographic Revision and Synopsis of the Trichoptera of the European Fauna. Part 4. 8vo. *London* 1876. The Author.

Orsoni (F.) Ricerche Elettro-Dinamiche sulle Rotazioni Paleogeniche. 4to. *Noto* 1876. The Author.

Preudhomme de Borre (A.) Notes sur des empreintes d'Insectes Fossiles découvertes dans les Schistes Houillers des Environs de Mons. 8vo. *Bruxelles.* The Author.

Rubenson (R.) Nederbördsmängden i Sverige härledd ur de Vid Statens Meteorologiska Stationer under Aren 1860–1872. Anställda Jakttagelser. 4to. *Stockholm* 1876. The Author.

Sopwith (T.), F.R.S. Description of a series of elementary Geological Models. 12mo. *London* 1875. The Author.

Taylor (W. B.) A Notice of recent Researches in Sound. 8vo. *New Haven* 1876. The Author.

April 27, 1876.

Transactions.

Amsterdam:—Koninklijke Akademie van Wetenschappen. Verhandelingen. Deel XV. 4to. 1875. Afdeeling Letterkunde. Deel VIII. 4to. 1875. Verslagen en Mededeelingen. Afdeeling Naturkunde. Tweede Reeks. Deel IX. 8vo. 1875. Jaarbock voor 1874. 8vo. Processen-Verbaal van de gewone Vergaderingen, 1874–75. 8vo. Carmina Latina. 8vo. 1875. The Academy.

Batavia:—Koninklijke Natuurkundige Vereeniging in Nederlandsch-Indie. Natuurkundig Tijdschrift. Deel XXXIV. 8vo. 1874. The Society.

Harlem:—Musée Teyler. Archives. Vol. IV. fasc. 1. roy. 8vo. 1876. The Museum.

Société Hollandaise des Sciences. Archives Néerlandaises des Sciences Exactes et Naturelles, rédigées par E. H. von Baumhauer. Tome X. liv. 4, 5; Tome XI. liv. 1. 8vo. *La Haye* 1875–76. The Society.

London:—Entomological Society. Transactions for the year 1875. Part 2–5. 8vo. The Society.

National Association for the Promotion of Social Science. Transactions. Brighton Meeting, 1875. Edited by C. W. Ryalls. 8vo. 1876. The Association.

Physical Society. Proceedings. Part 3. 8vo. 1876. The Society.

Quekett Microscopical Club. Journal. No. 23. 8vo. 1873. Seventh Report. 8vo. 1872. The Club.

Zoological Society. Transactions. Vol. IX. Part 5, 6, 7. 4to. 1875–76. Proceedings of the Scientific Meetings for 1875. Part 4. 8vo. 1876. The Society.

Madrid:—Instituto Geografico y Estadistico. Memorias. Tomo I. roy. 8vo. 1875. The Institution.

Observations &c.

Leiden:—Sternwarte. Annalen, herausgegeben von H. G. van de Sande Bakhuyzen. Band IV. 4to. *Haag* 1875. The Observatory.

Madrid:—Comision del Mapa Geologico de España. Memorias. Descripcion de la Provincia de Cuenca por Daniel de Cortazar. roy. 8vo. 1875. Boletin. Tomo II. roy. 8vo. 1875. The Commission.

Observatorio. Anuario. Año 11, 12. 12mo. 1871. Observaciones Meteorológicas, 1868–69, 1869–70. 2 vols. 8vo. 1870–71. Re-

Observations &c. (*continued*).

sumen de las Observaciones Meteorológicas efectuadas en la Peninsula, 1868-69, 1869-70. 2 vols. 8vo. 1871-72.
The Observatory.

Paris:—Bureau des Longitudes. Connaissance des Temps pour l'an 1877. 8vo. 1875. Annuaire pour l'an 1876. 12mo.
The Bureau.

Fraser (Dr. T. R.) On the Antagonism between the actions of Physostigma and Atropia. 4to. *Edinburgh* 1872. A Preliminary Notice of the Akazga Ordeal of West Africa. 8vo. 1867. On the Characters of the Akazga Plant. 8vo. 1868. Electrolysis in Aneurism. 8vo. 1867. An Investigation into some previously undescribed Tetanic symptoms produced by Atropia in Cold-blooded Animals. 8vo. 1868. Report on the Antagonism between the action of Active Substances. 8vo. 1872. Two Lectures. 8vo. 1872. On the Kombé Arrow-poison of Africa. 8vo. On the changes produced by direct Chemical Addition on the Physiological Action of certain Poisons. 8vo. 1868. The effects of Rowing on the Circulation. 8vo.
The Author.

Knop (Wilhelm) Körpermolcüle. Nachweisung der Thatsache, dass die Molecüle der neueren Chemie durch Zusammenlegen von Tetraedern und Oktaedern atomistisch nachgebildet werden können. 8vo. *Leipzig* 1876.
The Author.

Montefiore (Sir Moses), F.R.S. Narrative of a Forty Days' Sojourn in the Holy Land. roy. 8vo. *London* 1875.
The Author.

Mueller (Ferd. von), F.R.S. Descriptive Notes on Papuan Plants. I. 8vo. *Melbourne* 1875. Fragmenta Phytographiæ Australiæ. Vol. IX. 8vo. 1875.
The Author.

Walker (C. V.), F.R.S. Inaugural Address as President of the Society of Telegraph Engineers, January 12, 1876. 8vo. *London.*
The Author.

Bronze Medal struck to commemorate the completion of the great Hungarian Dictionary, by G. Czuczor and J. Fogarasi, with profiles of the compilers.
The Hungarian Academy.

Reports from the 'Challenger.'

I. "Preliminary Report to the Hydrographer of the Admiralty on some of the Results of the Cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso." By Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff on Board. Received February 26, 1876. Read March 23.

[Plates 15–19.]

To Captain Evans, C.B., F.R.S.

Sir,—I have the honour to report that we left Honolulu on the 11th of August, and on the 12th we sounded in 2050 fathoms, and took a series of temperature observations between the islands of Oahu and Hawaii. At night a crimson reflection was visible in the position of the top of Mauna Loa; but as we understood that the side crater of Kilauea only was in eruption, we supposed that that was some great conflagration of forest on the flank of the mountain. All the following day we steamed against a head wind along the rugged and picturesque coast of Hawaii—headlands of lava and volcanic ash separated by deep wooded ravines or "gulches," with a rapid hill-stream running in the bottom of each. The top of Mauna Loa was covered with clouds during the day; but at night a splendid crimson glare hung over the mountain, and lit up the clouds to a wide radius, and it became evident that we were fortunate enough to see one of the rare eruptions of the summit crater. Early on Saturday we cast anchor in Hilo Bay; and a party of us made arrangements to start as early as possible for the volcano of Kilauea thirty miles distant, intending, if the eruption of the summit crater continued and if we found it practicable, to push on to the top of the mountain. We left Hilo in the afternoon, taking magnetic and photographic instruments with us, and rode all night through the forest and over the lava-flows, reaching the rest-house at the side of the crater of Kilauea early in the morning. During the early part of the night the light from the summit crater was very brilliant, but it began to pale soon after midnight; and when we arrived at Kilauea we found that the column of smoke at the top of the mountain had almost entirely disappeared, and that the eruption was virtually over. This was no great disappointment to us; for we had learned that the ascent of the upper peak could not be undertaken with reasonable safety without much greater preparation in the way of provisions and warm clothing than we had had time to make, and we should have been obliged to give up the idea in any case. In the afternoon we went down into the crater and walked for about three miles over the nearly level lava of the eruption of 1868; we then clambered up to the ridge overlooking the two liquid lava-lakes, which have remained nearly in the same condition since 1868. We were greatly struck with the fluidity of the melted lava, which washed about in the basins with very much the appearance and sound of water. The night was perfectly still; and it had a most singular effect to see the two glowing lakes tossing like the sea in a storm, and a red surf dashing against the encircling rocks and springing forty or fifty feet into the air in wreaths of fiery spray. Lieutenant Bromley and I recrossed the lava-bed after nightfall, and our guide missed the ordinary path. In several places on either side of us the surface of the lava was glowing of a dull red, and we could see through the cracks the crust red-hot a couple of inches under our feet, and the liquid lava flowing beneath at the depth of about half a yard.

Observations were made by Lieutenant Bromley in the crater and on its rim with the "Fox" dip-circle for inclination and intensity, and with the prismatic compass for declination. Several excellent photographs of the crater were taken during the day. We returned to the ship on the evening of the 16th, and on the 19th we left Hilo and proceeded under sail for Tahiti, 2270 miles distant.

In the section between Hawaii and Tahiti, running almost directly southwards, we established 18 observing-stations at average intervals of 160 miles. At each of these stations the depth was taken, the bottom temperature was observed with two thermometers, a fair sample of the bottom was obtained, a specimen of the bottom-water was brought up for examination, serial temperature observations were made to a depth of 1500 fathoms, and at eight stations the trawl or dredge was sent down six times successfully, and twice unsuccessfully. Except at one station close to Tahiti, where the depth was 1525 fathoms, the depth ranged throughout the section from 2000 to 3000 fathoms, with a mean of about 2600 fathoms, and the nature of the bottom was very uniform. Except in the neighbourhood of the groups of volcanic islands, where it was found to be largely composed of volcanic débris and shore mud, it consisted mainly of red clay, in many of the soundings containing a large admixture of the decaying shells of Foraminifera, and in almost all including a large proportion of manganese peroxide in the form of concretions, from the size of a nut to that of an *Orbulina*, and passing into fine, almost microscopic granules visible under a low power in every sample of sounding. In two patches the siliceous skeletons of Radiolarians were so abundant as almost to entitle the deposit to the name of "Radiolarian ooze;" and a patch between these, nearly halfway between Hawaii and Tahiti, in its abundance of surface Foraminifera approached a true "*Globigerina*-ooze." The larger samples of bottom brought up in the dredge or trawl had, of course, the same general character as the contents of the "Bailie" sounding-tubes; but in these large manganese concretions, up to the size of an orange, or even larger, were collected in quantity, the greater part of the red clay being usually washed out.

The surface-temperature naturally rose in passing southwards from Hawaii towards the equator, and again sank from the equatorial belt towards Tahiti. The isothermobaths * between 14° C. and 24° C. gathered together and approached much nearer to the surface in the region of the trade-winds, owing no doubt to the rapid removal of the hot surface-water by evaporation and the driving action of the wind. Thus the isothermobathic line of 14° C., which is at a depth of 200 fathoms a little to the north of Tahiti, is at a depth of 100 fathoms on the line. In the Atlantic all the isothermobaths seem to participate in the rise in the region of the trade-winds: it is not so in the Pacific; the lines below 14° C. uniformly sink, forming a depression which extends from lat. 10° N. to lat. 10° S.; thus the isothermobath of 5° C., which may be taken as a type of these deeper lines, is found in lat. 10° N. at a depth of 450 fathoms, and in lat. 10° S. at the same temperature within the limits of error of observation, while in lat. 2° 34′ N. it is found at 625 fathoms. The point where the isothermobaths gather together most markedly and approach nearest to the surface is a little to the north of the northern border of the equatorial counter current. This fall of temperature is so decided as to indicate some special areas of cold water; and it may possibly be to some extent due to the pressing up of deeper and therefore colder layers of the colder trade-current against the hot stream. In the equatorial region between lat. 10° N. and 10° S. there is a belt of water about 80 fathoms in thickness at a temperature generally over 25° C.; and the whole of this water, with the exception of the narrow band of the counter current, is running to the westward at the rate of from 40 to 70 miles a day.

The bottom fauna over the whole of the manganese area is very meagre, both as to number of species and number of individuals. It can scarcely be said, however, that its scope and extent were fairly tested; for the presence of manganese nodules is almost fatal to the working of the trawl, which either becomes imbedded and impacted among them, producing a destructive strain on the line, or has the bottom torn out of the bag on the way up. Still in every haul in which the trawl was recovered

---

* The word *Isotherm* having been hitherto so specially appropriated to lines passing through places of equal temperature on the surface of the earth, I have found it convenient, in considering these questions of ocean temperature, to use the terms *Isothermobath* and *Isobathytherm*; the former to indicate a line drawn through points of equal temperature in a vertical section, and the latter a line drawn through points of equal depth at which a given temperature occurs. Isothermobaths are shown in a scheme of a vertical section, such as Plate 16. Isobathytherms are of course projected on the surface of the globe.

a few things occurred, usually in a very fragmentary condition. The following Table gives an idea of the proportion in which the principal groups were represented:—

	Station 264, 3000 faths.	Station 271, 2425 faths.	Station 272, 2600 faths.	Station 274, 2750 faths.	Station 276, 2350 faths.
Pisces	...	*	*	...	*
Cephalopoda.					
Gasteropoda	...	*			
Lamellibranchiata	...	*			
Brachiopoda	...	*			
Tunicata	...	*			
Pycnogonidæ.					
Decapoda	...	...	*	...	*
Schizopoda.					
Stomatopoda.					
Edriophthalmata.					
Phyllopoda.					
Ostracoda.					
Copepoda.					
Cirripedia.					
Annelida	...	...	*		
Gephyrea.					
Bryozoa	...	*			
Holothuridea	...	*	...	*	
Echinoidea	...	*	*		
Ophiuridea	...	*	*	...	*
Asteridea	...	...	...	*	
Crinoidea.					
Hydromedusæ.					
Zoantharia	...	...	...	*	
Alcyonaria	*	*	...	*	*
Porifera	*	*	*	*	
Rhizopoda	*	*	*	*	*

We took advantage of a week's stay at Tahiti to sound out the slope of this coral reef, and to determine the bathymetrical distribution of the species of reef-building corals. This investigation, which is not yet fully worked out, will form the subject of a separate report.

We left the harbour of Papeete on the 3rd of October, and proceeded southwards, expecting to pick up the westerly winds about lat. 40° S. We sighted the island of Tubuai on the 7th; and as we fell in with a succession of southerly instead of easterly winds, we were able to cut off a corner, and we reached the parallel of 40° in long. 132° 58′ W. From that point we ran along a little to the south of the parallel of 40°, encountering no regular westerly winds, but rather heavy weather from the south and north and calms, as far as long. 84° 39′ W., when we altered our course for the island of Juan Fernandez, steaming most of the time against foul winds from the north and north-east. We reached

Juan Fernandez on the evening of the 13th, and remained there two days observing and photographing the scenery, and making such collections of animals and plants as it was possible to make in so short a time. We weighed anchor on the evening of the 15th, and stood towards Valparaiso, where we arrived early on the 19th.

The section from Papeete to Valparaiso (Plate 17) is about 5000 miles in length, and is naturally divided into two parts—the run southwards to the parallel of 40° S., and the course along that parallel towards Valparaiso. In the entire section we established 20 stations bearing numbers from 279 to 298. At each of these the ordinary bathymetrical and temperature observations were taken successfully; and the trawl or dredge was lowered on thirteen occasions, twelve times successfully; on one occasion the trawl-line carried away.

Setting aside Station 279 in 680 fathoms close to Tahiti, the mean depth throughout the section was 2139 fathoms, considerably less than that of the meridional section from Honolulu to Tahiti, and very much less than that of the section in the North Pacific between Japan and San Francisco. The nature of the bottom is very much the same as in the meridional section, red clay imbedding nodules and lumps of various sizes of manganese peroxide, and passing in the shallower soundings into more or less pure *Globigerina*-ooze; and, as in the section between Hawaii and Tahiti, the fauna is generally meagre. The trawling between Juan Fernandez and Valparaiso (Station 298) was particularly interesting; animal forms were much more abundant than they usually are in the Pacific; and the general character of the assemblage resembled in a remarkable degree that of the fauna of the Southern Sea in the neighbourhood of the Crozets and Kerguelen, many of the species, including some singular Urchins of the family Ananchytidæ, being identical. The bottom at this station was a bluish mud, the surface layer containing little or no carbonate of lime, and, curiously enough, a deeper layer, with a considerable proportion of *Globigerina*-shells. There was no considerable quantity of manganese in the sounding. Notwithstanding the considerable depth of 2225 fathoms, the conditions in this locality seem much more favourable to animal life than even the manganese area; and I am inclined to think that we had struck upon one of the highways by which migration takes place to the northward from the Southern Sea. The following Table (p. 468) gives the proportion in which the principal animal groups are represented in the trawlings in this section.

From Tahiti to Station 288, in lat. 40° S., the upper temperatures fell regularly and steadily; but the isothermobaths below 80° C. showed rather a tendency to sink, indicating a somewhat thicker layer of water at a temperature above 3° C. towards the southward. The cause of this apparent anomaly will be discussed hereafter. From Station 289 the isothermobaths run on to Valparaiso with scarcely an oscillation of any importance (Plate 18).

	Station 279, 680 faths.	Station 280, 1940 faths.	Station 281, 2385 faths.	Station 285, 2375 faths.	Station 286, 2335 faths.	Station 289, 2550 faths.	Station 291, 2250 faths.	Station 293, 2025 faths.	Station 295, 1500 faths.	Station 296, 1825 faths.	Station 297, 1775 faths.	Station 298, 2225 faths.
Pisces	...	...	...	*	*	*	*	...	*			
Cephalopoda	...	...	...	...	...	...	...	...	...	...	...	*
Gasteropoda.												
Lamellibranchiata.												
Brachiopoda.												
Tunicata.												
Pycnogonidæ	...	...	...	...	...	...	...	...	...	...	...	*
Decapoda	*	...	*	*	...	*	...	...	...	*	...	*
Schizopoda.												
Stomatopoda.												
Edriophthalmata	...	...	*	...	...	...	...	...	...	...	...	*
Phyllopoda.												
Ostracoda.												
Copepoda	...	...	...	...	...	*						
Cirripedia.												
Annelida	...	...	...	*	*	*	...	...	...	*	...	*
Gephyrea	...	...	...	...	...	...	...	...	...	...	...	*
Bryozoa	...	*	...	...	...	...	*	*	...	*	...	*
Holothuridea	...	...	*	...	...	...	...	...	...	*	...	*
Echinoidea	...	...	...	...	...	...	...	...	...	*	...	*
Ophiuridea	...	...	...	*	...	...	...	...	...	*	...	*
Asteridea	...	...	...	...	*	*	...	...	...	*	...	*
Crinoidea.												
Hydromedusæ	...	...	...	...	...	...	*					
Zoantharia	...	...	...	...	*	...	...	*	...	*		
Alyonaria	...	...	...	...	*	...	...	*	...	...	...	*
Porifera	...	*	*	...	*	*	*	*	...	*	*	*
Rhizopoda	...	*	*	*	*	*	*	*	...	*	*	*

Although there are certain points which have yet to be worked out in detail, the general distribution of temperature in the Pacific seems sufficiently simple. In the first place, the whole mass of water consists of two well-marked divisions—an upper layer of no great depth, in which there is rapid cooling from the surface downwards, and considerable variation in temperature in different localities; and a mass of water of incomparably greater amount, which extends to the bottom, and which may be said to have nearly the same temperature throughout. These two divisions shade into one another; but the isothermobath of 5° C. may be taken as indicating generally the limit between them; below this line the isothermobaths are still affected by surface thermal conditions, but comparatively slightly. Above the line of 5° C. the course of the isothermobaths is to all appearance entirely regulated by causes affecting the surface-temperature—that is to say, directly or indirectly, by surface currents produced by permanent, periodic, or variable winds. The equatorial current occupies the region of the trade-winds, approximately from lat. 20° N. to 20° S., and there is a strong but narrow counter current, entirely comparable with the counter current in the Atlantic between the parallels of 5° and 8° N. The water of the equatorial current has no free egress to the westward, being intercepted by the peninsula of Malacca and the islands of the Malay archipelago; but neither is it completely arrested, as the equatorial current is in the Atlantic by the unbroken coast of America; consequently a return current, less permanent and less defined than the return current in the Atlantic, finds its way to the north-eastward along the coast of Japan. The course of the Japan current is much the same as that of the Gulf-stream, and is due, as in the Atlantic return current, to the high initial velocity of the intercepted water; its influence on the temperature of the ocean is, however, much sooner reduced and obliterated.

The hot water of the Pacific equatorial current instead of being gathered together and focused by the form of the land-barrier, as it is in that of the Atlantic, spreads out in the Middle and West Pacific in a vast sheet of abnormally warm water, extending to a depth of nearly 100 fathoms; thus the isobathytherm of 25° C. at 80 fathoms passes near Hawaii and Tahiti, and near the parallel of 20° N. on sections between the Admiralty Islands and Japan. The lower isothermobaths of the upper layer are a little nearer the surface in lat. 40° N. than in lat. 40° S.; and this I believe to be due to the banking of the Antarctic indraught against the Arctic land-barrier, and to be the only case in which the position of the lines of equal temperature in the upper layer is not absolutely dependent upon the wind.

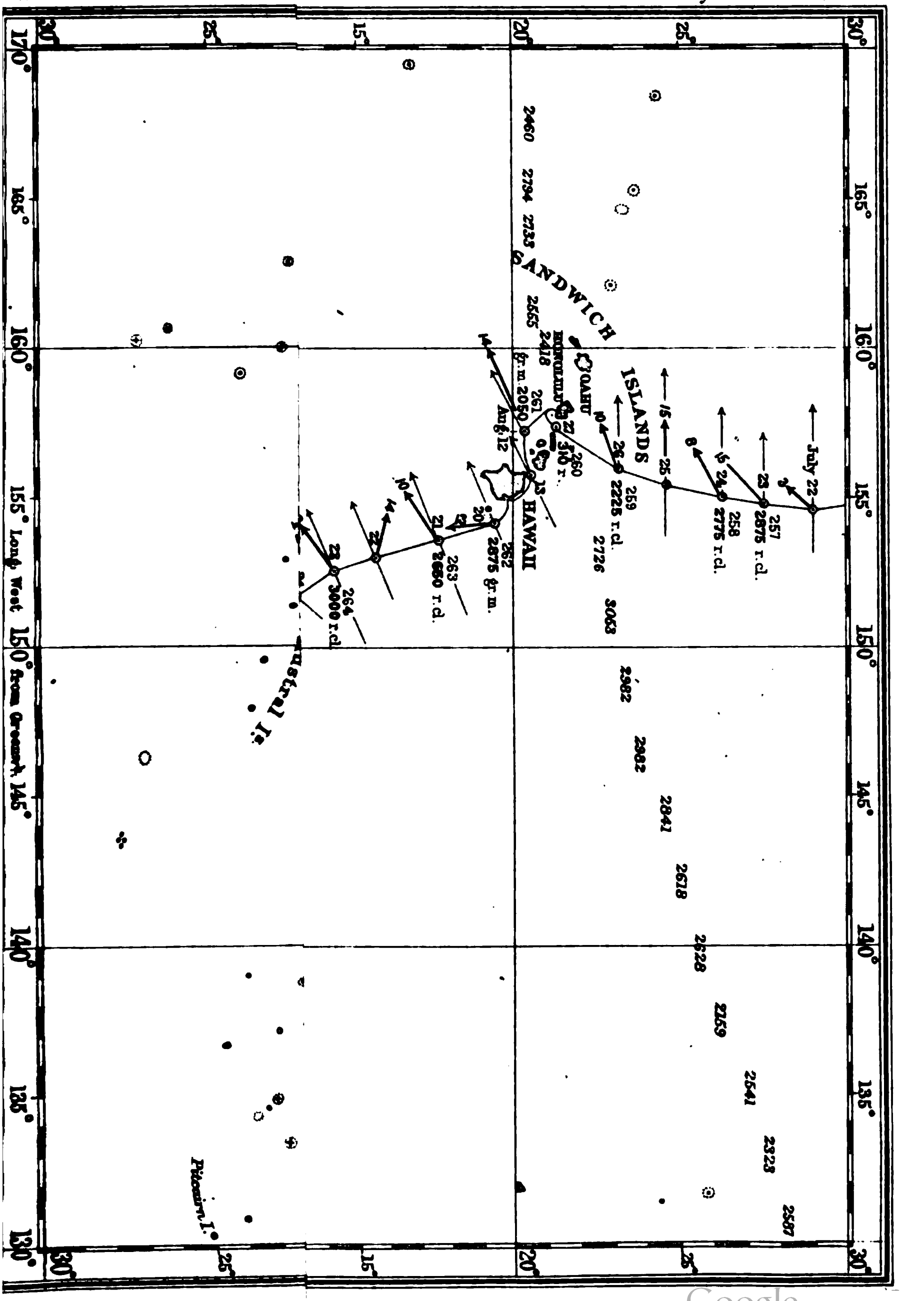
The temperature of the underlying cold water is derived from another source, and its distribution is governed by other laws. Throughout the Pacific the isothermobath of 5° C. maintains on the whole a very even course, oscillating between the 400- and 500-fathom lines. These oscillations depend upon causes acting on the surface, for the line rises and falls in harmony with the higher isothermobaths. The line of 5° C. deviates sensibly on two occasions from its comparatively straight course. In the equatorial region it sinks to a depth of 625 fathoms, probably from the communication of heat from the upper layer of water by mixing; and in lat. 40° it rises to 300 fathoms, probably, as I have already said, from the accumulation of cold water against the Arctic barrier. The next three degrees of temperature are lost with increasing slowness in the next 700 fathoms, the line of 2° C. making a very even course at a depth of 1100 fathoms, and the remaining degree or degree and a fraction is lost between 1100 fathoms and the bottom. The depth of the Pacific increases slowly from the south to the north, the mean difference between the depth of the South Pacific and that of the North being perhaps as much as 1000 fathoms (see Plate 19, and the results of the soundings of the 'Tuscarora'). Notwithstanding this increase in depth, we have satisfied ourselves, although the determination is one of great difficulty, that the bottom-temperature rises slightly from the south northwards. We can scarcely say more than that it rises slightly; for the differences in the temperatures below 1500 fathoms are so small that a result can only be arrived at by a careful combination and comparison of many observations, taking into full consideration the errors of the thermometers arising from all sources. There is a like very slight decrease in the bottom-temperatures from east to west.

I think we can scarcely doubt, looking at such a diagram as Plate 19, that, like the similar mass of cold bottom-water in the Atlantic, the bottom-water of the Pacific is an extremely slow indraught from the Southern Sea. That it is moving, and moving from a cold source, is evident from the fact that it is much colder than the mean winter temperature of the area which it occupies, and colder than the mean temperature of the crust of the earth; that it is moving in one mass from the southward is shown by the uniformity of its conditions, by the gradual rise of the bottom-temperatures to the northward, by the fact that there is no adequate northern source of such a body of water (Behring's Strait being only 40 fathoms deep, and a considerable part of that area being occupied by a warm current from the Pacific into the Arctic Sea), and by our knowlege from observations that one or two trifling currents from the Sea of Okotsk and the Behring Sea, which are readily detected and localized, and are quite independent of the main mass of cold water, represent the only Arctic influx. During its progress northwards the upper portion of the mass becomes slightly raised in temperature by mixture with, and possibly by slow conduction from, the upper layers which are affected by solar heat. At the end of the Gulf (that is to say in the extreme north, furthest from the cold source) the temperature is, as I have already pointed out, influenced to the very bottom; and the isothermobaths between 8° and 5° C. are obviously raised and pressed together, probably by the accumulation of the cold water against the land. The colder bottom-water to the westward might be expected, from the lower initial velocity of the Antarctic water causing it to drag against the west coast.

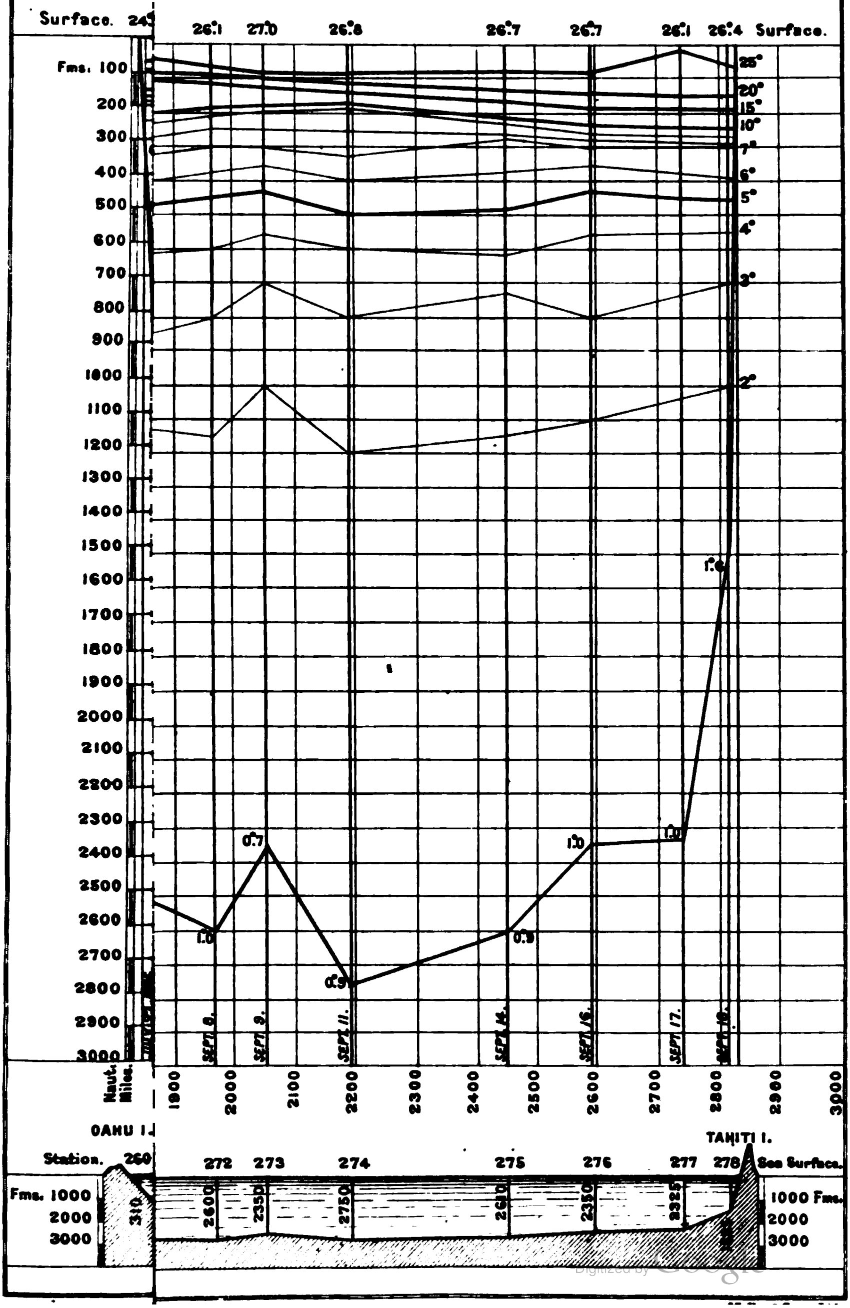
I am every day more fully satisfied that this influx of cold water into the Pacific and Atlantic oceans from the southward is to be referred to the simplest and most obvious of all causes, the excess of evaporation over precipitation in the northern portion of the land hemisphere, and the excess of precipitation over evaporation in the middle and southern part of the water hemisphere.

After what I have already said I need scarcely add that I have never seen, whether in the Atlantic, the Southern Sea, or the Pacific, the slightest ground for supposing that such a thing exists as a general vertical circulation of the water of the ocean depending upon differences of specific gravity.

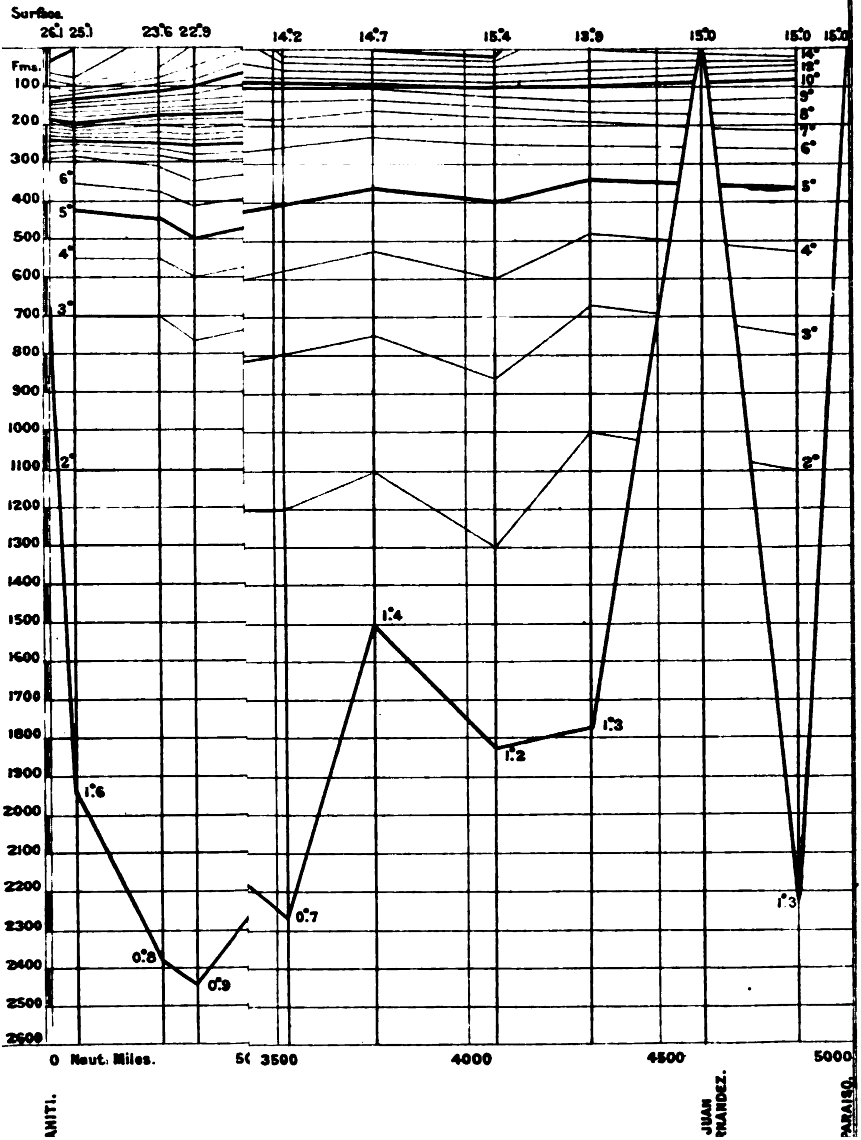
Valparaiso,
Dec. 5, 1875.


170°
165°
160°
155° Long. West 150° from Greenwich 145°
140°
135°
130°
30°
25°
20°
15°
SANDWICH ISLANDS
OAHU
HONOLULU
HAWAII
Austral Is.
Pitcairn I.
July 22
23
24
25
26
Aug. 12
13
20
21
22
23
257
2875 r.cl.
258
2775 r.cl.
259
2225 r.cl.
260
310 r.
261
gr.m. 2050
262
2875 gr.m.
263
2650 r.cl.
264
3000 r.cl.
2460
2794
2733
2565
2418
2726
3063
2962
2962
2841
2618
2628
2759
2541
2323
2587

OF TEMPERATURE

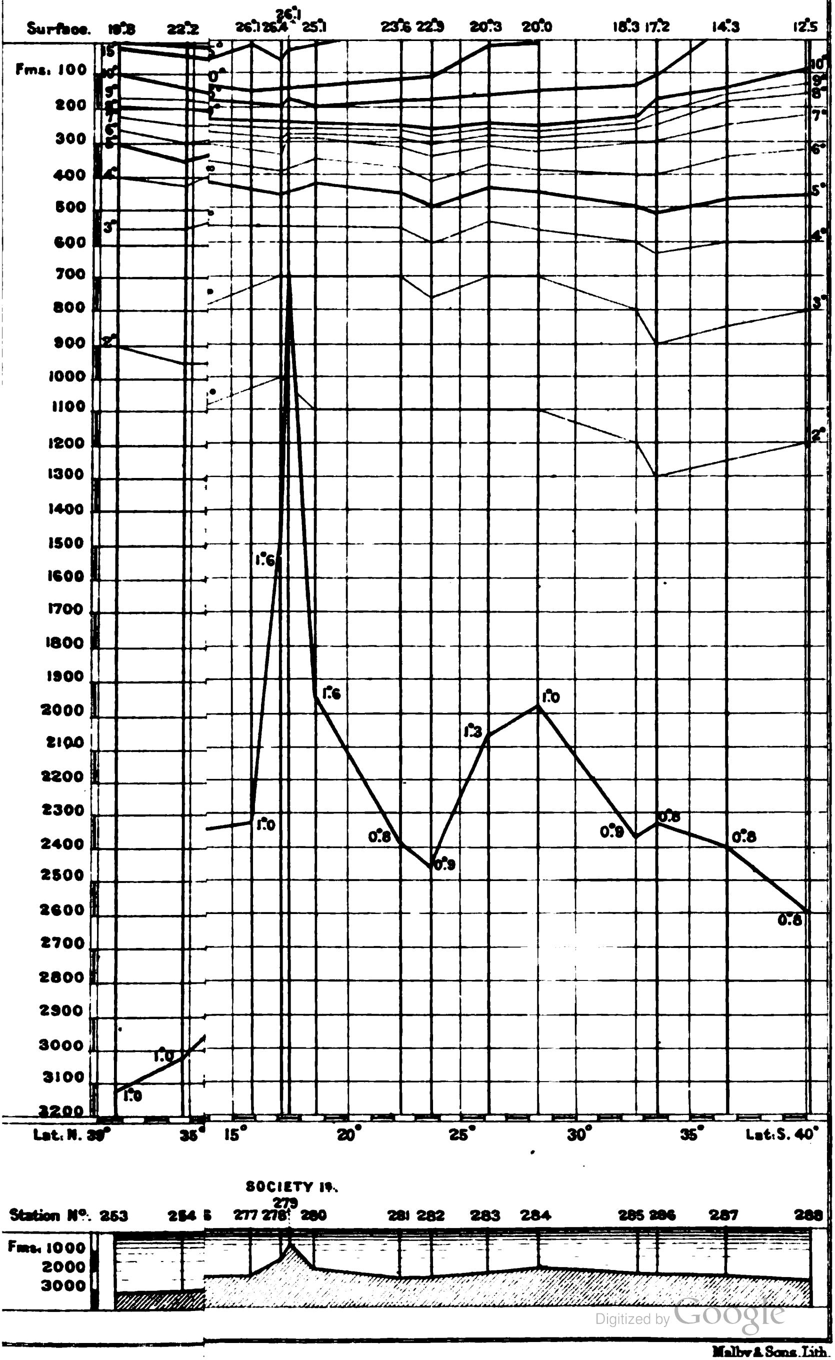


EMPERATURE

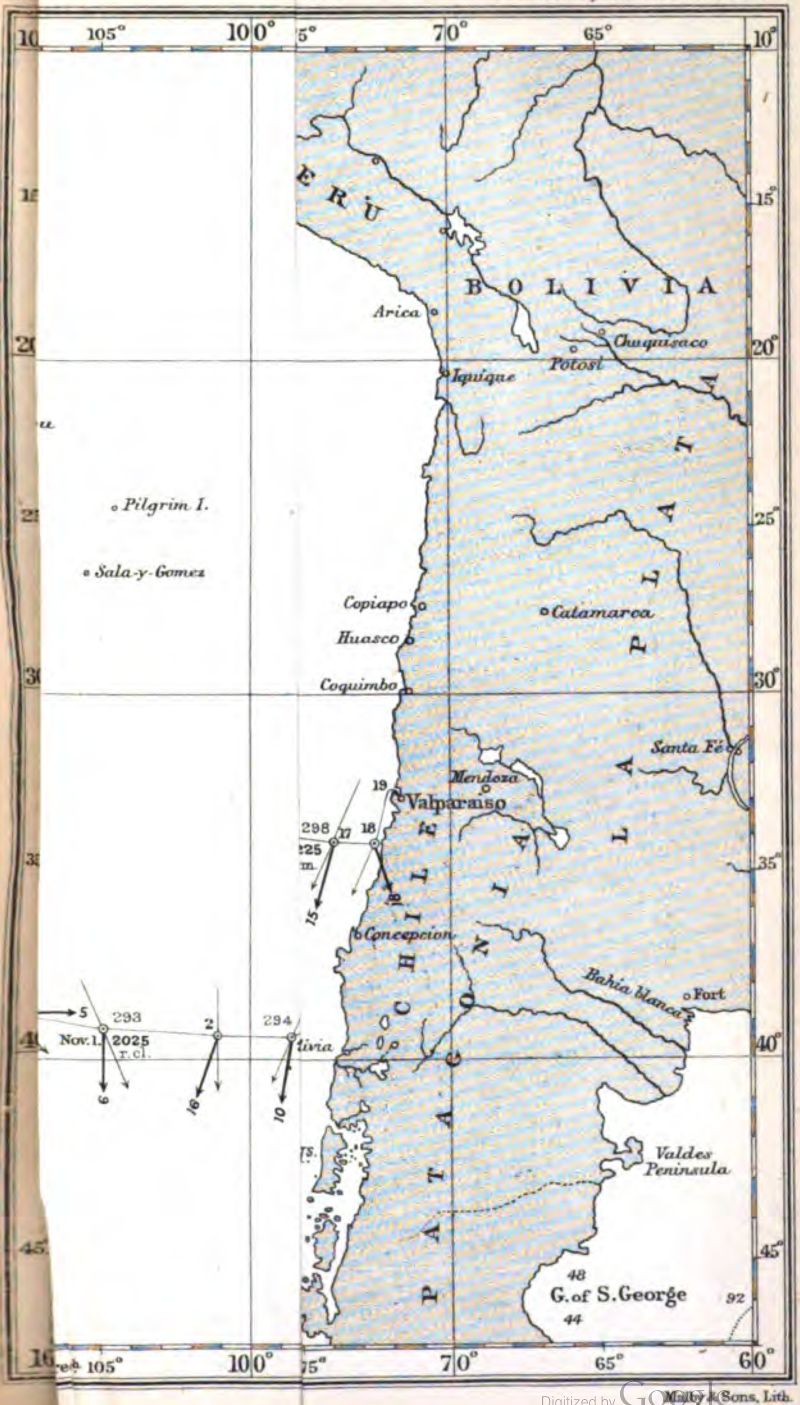

Surface
26.1 25.1 23.6 22.9 14.2 14.7 15.4 13.9 15.0 15.0 15.0
Fms.
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
14°
12°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1.6
0.8
0.9
0.7
1.4
1.2
1.3
1.3
0 Naut. Miles.
5(
3500
4000
4500
5000
AHITI.
JUAN
RNANDEZ.
PARAISO.

Thomson. *Proc. Roy. Soc. Vol: 24, Pl: 18.*

TEMPERATURE
SOUTH.



Malby & Sons. Lith.


105°
100°
75°
70°
65°
60°
10°
15°
20°
25°
30°
35°
40°
45°
PERU
BOLIVIA
Arica
Iquique
Potosi
Chuquisaco
LA PLATA
Pilgrim I.
Sala-y-Gomez
Copiapo
Huasco
Coquimbo
Catamarca
Santa Fé
Mendoza
Valparaiso
CHILE
PATAGONIA
19
298
17
18
225
15
Concepcion
Bahia blanca
Fort
5
293
Nov. 1.
2025
r.cl.
2
294
6
16
10
Valdes Peninsula
48
G. of S. George
44
92

II. "Preliminary Reports to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work done on board the 'Challenger.'" By John Murray, Esq., Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received Feb. 14, 1876. Read March 16.

[Plates 20–24.]

Page
1. Preliminary Report on Oceanic Deposits 471
2. Preliminary Report on some Surface Organisms and their relation to Oceanic Deposits 532
3. Preliminary Report on Vertebrates 537

Preface to Preliminary Reports.

The Preliminary Reports have been prepared at the request of Professor Wyville Thomson. They have been compiled during the past three weeks from notes taken daily during the past three years. In only a few cases has it been possible to refer to the objects remarked upon, they having been sent home for greater safety, or packed away beyond reach. When specimens taken early in the cruise can be placed side by side and compared with the more recent revelations of the trawl, dredge, or sounding-tube, many of the statements herein made may require to be modified.

Reports on three years' work, prepared under the disadvantages above mentioned, must necessarily be very incomplete; and indulgence may be asked till the final Report can be issued.

To all my coadjutors, naval and civilian, I am indebted for much assistance, especially to Mr. Wild for his drawings, to Mr. Buchanan for much information concerning the chemical constituents of the bottoms, and to Professor Thomson for assistance and advice, not only in preparing these Reports, but also while carrying on the investigations of which they are intended to give some account.

JOHN MURRAY.

Valparaiso, Chili,
9th December, 1875.

1. Preliminary Report on Specimens of the Sea-bottoms obtained in the Soundings, Dredgings, and Trawlings of H.M.S. 'Challenger,' in the years 1873–75, between England and Valparaiso.

Method of Work.—During the first six months of the expedition the sounding-apparatus in use on board was provided with a very narrow cylinder, which brought up only a very small quantity of the bottom.

In July 1873 Capt. Nares had a much larger cylinder fitted to the instrument, one with a 2-inch bore; and later on he caused the weights to be so arranged with respect to the cylinder that the latter projected some 18 inches beneath the former.

This arrangement, the cylinder of which is always provided with the common butterfly-valve, usually gives us a very large quantity of the bottom in each sounding. Sometimes the tube has been forced fully 18 inches into the bottom, and has brought up frequently as much as a quart of the ooze, mud, or clay. When the tube arrives on board the contents are carefully removed, and the colour, extent, and arrangement of the section* is noted. A portion is washed several times in distilled water and dried, a portion is submitted to a rough analysis, and the remainder, if any, is preserved in spirit.

The analysis consists in determining so far as possible :—

1. The kinds of organisms present, and their relative abundance, whether carbonate of lime or siliceous, and whether alive or dead.

2. The kind and quantity of amorphous and mineral matter, and its ratio to the remains of the above organisms.

This is accomplished by decanting the finer from the coarser particles, and examining each with the microscope. When carbonate of lime is present this is removed by weak acid, and the specimen is again examined. When manganese is present in great quantity this is removed by strong hydrochloric acid, and again an examination is made. Very frequently portions of the upper layers are placed in colouring solutions (as carmine, magenta, &c.), for the purpose of rendering more distinct any organized material, should any be present.

When the dredge or trawl brings up mud, a considerable quantity is preserved for future work, and what remains is carefully sifted. The siftings are examined and preserved.

Lately it has been the custom to send down tow-nets loosely attached to the trawl or dredge and at the weights in front of the trawl. These often bring up specimens of the bottom when the trawl fails to do so. As these nets do not probably sink deep into the ooze, they give us a surer idea of the nature of the surface-layers than previously obtained by the trawl alone.

List of the Soundings and Dredgings, with an abstract of the nature of the bottom in each case where a sample has been procured.

Explanatory Note.—The following remarks under each sounding or dredging have been abstracted from notes made daily during the cruise. In making the abstract the object in view has been to indicate so far as possible the relative abundance in each sample of—

Remains of carbonate-of-lime organisms ;
Remains of siliceous organisms ;
Mineral particles, as quartz and mica ;
Glauconite, pumice, manganese, &c. ; and
Amorphous clayey and calcareous matter.

It has been thought that, however incomplete, such an abstract will in the mean time be useful to naturalists and geologists. It will give some idea of the nature and distribution of the deposits which are taking place in the oceans and seas we have visited. It will also furnish some data and serve as the basis for speculations on the mode of origin of—

---

* *i. e.* the vertical section, which is always greater the further the tube has been forced into the ooze or clay.

The deep-sea clays;
The formation of the manganese nodules;
The presence of the remains of surface animals (consisting of siliceous and carbonate-of-lime organisms) in some deposits, and their absence in others, &c.

By pelagic Foraminifera are meant species of *Globigerina*, *Orbulina*, *Pulvinulina*, and of one or two other genera which are still undescribed, but which have been found abundantly in the surface-waters of the Pacific and South Atlantic oceans.

When the final Report is prepared, the genera or species of the organisms whose remains occur in each sample will be given. So also for the mineral particles, and the ratio of these to each other and to the amorphous, clayey, and calcareous matter will be more accurately stated. At the present moment such an undertaking is in no way possible. Those things which are most abundant in the sample are generally mentioned first.

ATLANTIC OCEAN.

England to Gibraltar.

30th December, 1872. Lat. 41° 37′ N., long. 9° 42′ W. 1125 fathoms. A blue mud containing:—Amorphous blue clayey matter; many fine mineral particles; many pelagic Foraminifera and Coccoliths and Coccospheres.

Sounding 1. 13th January, 1873. Lat. 38° 10′ N., long. 9° 14′ W. 470 fathoms. A green mud containing:—Amorphous clayey matter; many sandy particles; pelagic and other Foraminifera; spicules of sponges; pieces of Corallites. Light green-coloured glauconitic casts of the Foraminifera remained after treatment with acid.

Sounding 3. 14th January, 1873. Lat. 38° 26′ N., long. 9° 38′ W. 560 fathoms. A dark green mud containing:—Amorphous matter and many dark green grains and other mineral particles; pelagic and other Foraminifera, *Echini*-spines, &c. Beautiful glauconitic casts of all the carbonate-of-lime organisms remained after treatment with acid.

Sounding 4. 14th January, 1873. Lat. 38° 22′ N., long. 9° 44′ W. 1290 fathoms. A blue mud containing:—Much amorphous matter; many black, green, and white mineral particles; many pelagic Foraminifera and few shells of Mollusca; a few casts of the Foraminifera in glauconite.

Sounding 5. 14th January, 1873. Lat. 38° 14′ N., long. 9° 49′ W. 1475 fathoms. A blue mud containing:—Amorphous matter; many fine and some coarse mineral particles of green, white, and black colour; some pelagic Foraminifera and Coccoliths. One or two green casts of the Foraminifera remained after treatment with acid.

Sounding 6. 14th January, 1873. Lat. 38° 9′ N., long. 9° 43′ W. 1380 fathoms. A blue mud containing:—Amorphous matter; many fine mineral particles, white and green; a few pelagic Foraminifera and many Coccoliths; a few green casts of the Foraminifera.

Sounding 7. 14th January, 1873. Lat. 37° 56′ N., long. 10° 8′ W. 1800 fathoms. A blue mud containing:—Much amorphous clayey matter; many small mineral particles; a few pelagic Foraminifera, Coccoliths, and Rhabdoliths.

Sounding 8. 15th January, 1873. Lat. 37° 2′ N., long. 9° 23′ W. 1000 fathoms. A blue mud containing:—Much amorphous matter; many fine mineral particles, white and green; some pelagic and other Foraminifera and Coccoliths; many green casts (glauconitic) of the Foraminifera after treatment with acid.

Soundings 9, 10, & 11. Lat. 36° 58′ N., long. 9° 14′ W., and lat. 37° 2′ N., long. 9° 14′ W. 525, 900, and 600 fathoms respectively. Gave a blue mud, as in No. 3.

Gibraltar to Madeira.

Sounding 12. 28th January, 1873. Lat. 35° 47′ N., long. 8° 23′ W. 1090 fathoms. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few white mineral particles; one or two Radiolarian remains; amorphous calcareous matter.

Sounding 14. 30th January, 1873. Lat. 36° 23′ N., long. 11° 18′ W. 1525 fathoms. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few white, red, and black mineral particles; one or two Radiolaria; amorphous calcareous matter.

Sounding 16. 1st February, 1873. Lat. 34° 4′ N., long. 14° 18′ W. 2250 fathoms. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few small white crystalline particles; one or two Radiolaria; some amorphous calcareous matter.

Sounding 17. 2nd February, 1873. Lat. 32° 43′ N., long. 15° 52′ W. 2225 fathoms. A yellow *Globigerina*-ooze containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a good many mineral particles (Olivinite); a few manganese grains; a few Radiolaria.

Sounding 18. 2nd February, 1873. Off Madeira Island. 670 fathoms. A sand composed of broken pieces of coral, *Lepas*-valves, *Echini*-spines, pelagic and other Foraminifera (these were all dead, and had a slight coating of the black oxide of manganese); many olivine and other mineral particles.

Sounding 19. 2nd February, 1873. South of Bugro Island. 1150 fathoms. A grey mud containing:—Much volcanic sand, as olivinite; pelagic Foraminifera and Gasteropod, Pteropod, and Heteropod shells, Coccoliths; a few siliceous spines, but no Radiolaria were observed.

Sounding 20. 2nd February, 1873. 930 fathoms. A grey mud containing:—Much volcanic sand and many very fine mineral particles; a few pelagic Foraminifera, Pteropods, and surface Gasteropods, a few Coccoliths; no siliceous remains were observed.

Sounding 21. 2nd February, 1873. 1500 fathoms. A grey mud containing:—Much volcanic sand (red, white, and black particles and olivine); a good many pelagic Foraminifera; Pteropod, surface Gasteropod, and Heteropod shells; Coccoliths and Rhabdoliths; a few siliceous spines and Radiolaria.

At Canaries.

Sounding 25. 10th February, 1873. 278 fathoms. A dark grey mud or sand containing:—Many volcanic sandy particles; a few pelagic Foraminifera, Pteropods, Gasteropods, and Coccoliths; one or two siliceous spines.

Soundings 26 and 28. At 630 and 560 fathoms respectively. The same as No. 25.

Sounding 29. 10th February, 1873. 78 fathoms. A coarse sand formed of débris of volcanic rocks, with pieces of Echinoderms, Foraminifera, molluscous shells, &c.

Sounding 31. 10th February, 1873. 640 fathoms. Off Teneriffe. A grey mud containing:—Much volcanic sand, black, white, and red in colour, and olivine; some pelagic Foraminifera, Pteropods, pelagic Gasteropods, and Heteropod shells; a few Coccoliths; one or two Radiolaria.

Sounding 33. 11th February, 1873. 1750 fathoms. A grey mud containing:—Very many fine particles of volcanic sand of black, white, and red colour, and amorphous clayey matter; a good many pelagic Foraminifera and Coccoliths; one or two Radiolaria.

Sounding 36. 12th February, 1873. 620 fathoms. A grey mud containing:—Very many particles of volcanic sand and amorphous clayey matter; many pelagic Foraminifera, Pteropods, and other surface shells.

Sounding 37. 15th February, 1873. 1800 fathoms. Lat. 27° 24′ N., long. 16° 55′ W. A grey mud containing:—Many fine particles of volcanic sand of white, black, and red colour; pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few Radiolaria.

Sounding 38. 17th February, 1873. 1945 fathoms. Lat. 25° 15′ N., long. 19° 14′ W. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera and Coccoliths and some Pteropod shells; a few mineral particles.

Soundings 39 & 40. 18th February, 1873. 1525 fathoms. Lat. 25° 45′ N., long. 20° 12′ W. Nothing in the sounding-tube.

The dredge brought up a large quantity of dead coral, a branching gorgonoid. The axis of this coral was white; but the surface was black, with a thick coating of manganese. Some pelagic Foraminifera and Pteropod shells adhered to the base of the coral, and about a large siliceous sponge.

Sounding 42. 21st February, 1873. 2740 fathoms. Lat. 24° 20′ N., long. 24° 28′ W. A red clay containing:—Much amorphous matter; very many exceedingly fine mineral particles; a few whole and a good many broken parts of pelagic Foraminifera; one or two Radiolaria.

Sounding 43. 23rd February, 1873. 2950 fathoms. Lat. 23° 22′ N., long. 27° 49′ W. A red clay containing:—Amorphous matter and many very fine mineral particles; a good many pelagic Foraminifera and their broken parts.

Sounding 44. 24th February, 1873. 2750 fathoms. Lat. 23° 15′ N., long. 30° 56′ W. A red clay containing:—Much amorphous matter; mineral particles, all exceedingly fine and in immense numbers; a few remains of broken pelagic Foraminifera; no siliceous remains observed.

Sounding 45. 25th February, 1873. 2800 fathoms. Lat. 23° 12′ N., long. 32° 56′ W. A red clay containing:—Much amorphous matter and very many exceedingly fine mineral particles; a few broken remains of pelagic Foraminifera.

Sounding 46. 26th February, 1873. 3150 fathoms. Lat. 23° 23′ N., long. 35° 10′ W. A red clay containing:—Much amorphous matter and many very small mineral particles; a few broken pieces of pelagic Foraminifera; a few manganese grains.

Sounding 47. 28th February, 1873. 2720 fathoms. Lat. 23° 10′ N., long. 38° 42′ W. A red clay containing:—Much amorphous matter; very many small white and red mineral particles; a few pelagic Foraminifera.

Sounding 48. 1st March, 1873. 2575 fathoms. Lat. 22° 35′ N., long. 40° 37′ W. A red clay containing:—Much amorphous matter; very many exceedingly fine mineral particles; a good many pelagic Foraminifera, Coccoliths, and Rhabdoliths.

Sounding 49. 3rd March, 1873. 2025 fathoms. Lat. 21° 57′ N., long. 43° 29′ W. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a great many manganese particles, many of them rather large; many pieces of a cherty-like mineral of a red colour (a silicate); a few white mineral particles.

Sounding 50. 4th March, 1873. 1900 fathoms. Lat. 21° 38′ N., long. 44° 39′ W. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; many red-coloured mineral particles, and a few manganese particles.

Sounding 51. 5th March, 1873. 1950 fathoms. Lat. 21° 1′ N., long. 46° 29′ W. A *Globigerina*-ooze of a red colour containing:—Very many pelagic Foraminifera, Rhabdoliths, and Coccoliths; many very fine white-coloured mineral particles (sanidin); a good many small manganese particles, to which the colour of the sounding is to some extent due.

Sounding 52. 6th March, 1873. 2325 fathoms. Lat. 20° 49′ N., long. 48° 45′ W. A *Globigerina*-ooze of rose-colour containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; much amorphous matter, and very many fine white mineral particles; a few Radiolarian remains.

Sounding 53. 7th March, 1873. 2435 fathoms. Lat. 20° 39′ N., long. 50° 33′ W. A red clay containing:—Much amorphous clayey matter; many fine white and red mineral particles; a few manganese particles; a good many remains of pelagic Foraminifera, Coccoliths and Rhabdoliths; a few Radiolarians.

The dredge brought up some grey-coloured concretions covered with manganese, also a few sharks' teeth and valves of a *Scalpellum* covered with a thin coating of manganese.

Sounding 54. 8th March, 1875. 2385 fathoms. Lat. 20° 7′ N., long. 52° 32′ W. A red clay containing:—Much amorphous matter; many exceedingly fine mineral particles; many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few manganese grains.

Sounding 55. 10th March, 1873. 2675 fathoms. Lat. 19° 41′ N., long. 55° 13′ W. A red clay containing:—Much amorphous clayey matter; many very small crystalline particles; a few whole and some broken parts of pelagic Foraminifera.

Sounding 56. 11th March, 1873. 3000 fathoms. Lat. 19° 15′ N., long. 57° 47′ W. A red or grey clay containing:—Amorphous matter and exceedingly fine mineral particles; a small piece of shell and a portion of a siliceous spine were the only traces of organisms; a few manganese particles.

Sounding 57. 12th March, 1873. 2975 fathoms. Lat. 18° 56′ N., long. 59° 35′ W. A red clay containing:—Much amorphous matter and very many exceedingly fine mineral particles; a few remains of pelagic Foraminifera; one or two portions of a siliceous spine.

Sounding 58. 13th March, 1873. 3025 fathoms. Lat. 18° 54′ N., long.

61° 25′ W. A red clay containing:—Much amorphous matter; many small white and yellow-coloured mineral particles; three small fragments of *Globigerina* and two pieces of a siliceous spine were the only traces of organisms noticed.

Sounding 59. 14th March, 1873. 1420 fathoms. Lat. 18° 40′ N., long. 62° 56′ W. A *Globigerina*-ooze containing:—Many pelagic Foraminifera; Pteropods, pelagic Gasteropods, Heteropods, Coccoliths, and Rhabdoliths; a few mineral particles of a white colour; a few Radiolaria and siliceous spines.

Sounding 60. 15th March, 1873. 460 and 390 fathoms. North of Calebra Island. A coral mud containing:—Many pelagic Foraminifera, Pteropods, Heteropods, small larval Gasteropods; *Echini*-spines; a few Coccoliths; a good many rather coarse mineral particles of white and black colour; a good many siliceous spines and Radiolaria; amorphous calcareous matter; one cast of a Foraminifer of a red colour.

St. Thomas's to Bermuda.

Station 24. 25th March, 1873. 390 and 625 fathoms. North of Calebra Island. A coral mud containing:—Much amorphous calcareous matter; a good many remains of pelagic Foraminifera, Pteropods, surface Gasteropods, Coccoliths, and Rhabdoliths; a good many small white crystalline particles; one or two casts of Foraminifera in a dark red substance.

Sounding 61. 26th March, 1873. 3875 fathoms. Lat. 19° 41′ N., long. 65° 7′ W. A blue mud (red on the top, then a layer of blue or slate-colour, the lower layers of a grey colour) containing:—Much amorphous matter; many very small crystalline or mineral particles; a good many broken pieces of pelagic Foraminifera; Pteropods and Heteropods; a few Coccoliths and Rhabdoliths. The lower layers appeared to contain more carbonate of lime than the upper ones.

Sounding 62. 27th March, 1873. 2800 fathoms. Lat. 21° 26′ N., long. 65° 16′ W. A red clay containing:—Much amorphous matter; very many fine mineral particles; a few remains of pelagic Foraminifera, and one or two Coccoliths; one or two manganese grains.

Sounding 63. 28th March, 1873. 2960 fathoms. Lat. 22° 49′ N., long. 65° 19′ W. A red clay containing:—Much amorphous clayey matter; very many exceedingly fine mineral particles; a few broken remains of pelagic Foraminifera.

Sounding 64. 29th March, 1873. 2850 fathoms. Lat. 24° 39′ N., long. 65° 25′ W. A red clay containing:—Much amorphous clayey matter; many exceedingly fine white mineral particles; a few broken remains of pelagic Foraminifera; one or two manganese grains.

Sounding 65. 31st March, 1873. 2700 fathoms. Lat. 27° 49′ N., long. 64° 59′ W. A red clay containing:—Much amorphous matter; many very fine mineral particles; a good many remains of pelagic Foraminifera and Coccoliths; no remains of siliceous organisms were observed.

The dredge brought up much mud; in the siftings were found:—a few manganese pellets; a few arenaceous Foraminifera, Nodosarias, &c.; *Biloculina*, *Rotalia*, and *Carpenteria* on a concretion; a few pieces of red cherty-like mineral; a few concretions of the bottom; a small piece of pumice (?); one *Echinus*-spine; a small shark's tooth.

The tests of the arenaceous Foraminifera were chiefly small, white, mineral particles; and these, I think, are from broken-down pieces of pumice.

Sounding 66. 1st April, 1873. 2600 fathoms. Lat. 29° 5′ N., long. 65° 1′ W. A red clay containing:—Much amorphous matter; many very fine mineral particles; a good many pelagic Foraminifera, with Coccoliths and Rhabdoliths.

Sounding 67. 3rd April, 1873. 2475 fathoms. Lat. 31° 24′ N., long. 65° 00′ W. A red clay containing:—Much amorphous clayey matter; many fine crystalline and mineral particles; a good many pelagic Foraminifera, Coccoliths, and Rhabdoliths, and some amorphous calcareous matter; one siliceous spine, but no Radiolaria observed.

Sounding 68. 3rd April, 1873. 2250 fathoms. Lat. 31° 49′ N., long. 64° 55′ W. A coral-mud containing:—Many pelagic Foraminifera, Coccoliths, Rhabdoliths, and broken pieces of dead coral; amorphous calcareous matter; a few mineral particles (some green); a few siliceous spines and Radiolaria.

Sounding 69. 3rd April, 1873. 1820 fathoms. Lat. 32° 1′ N., long. 64° 50′ W. A coral-mud containing:—Many pelagic Foraminifera, Pteropods, and other surface shells, Coccoliths, and Rhabdoliths; broken pieces of Coral, Polyzoa, and *Echini*-spines; amorphous calcareous matter.

Sounding 70. 30th April, 1873. 950 fathoms. A coral-mud containing:—Pelagic Foraminifera, Pteropods, and surface Gasteropods; broken pieces of Coral, Polyzoa, &c.; much amorphous calcareous matter; a few siliceous spines and Radiolaria.

Sounding 70 A. 4th April, 1873. 435 fathoms. Off Bermuda. A coral-mud containing:—Much amorphous calcareous matter; pelagic and other Foraminifera, Pteropods, &c.; broken pieces of Coral, Polyzoa, &c.; a few siliceous spines.

Soundings off the reef at Bermuda, about a mile from the edge of the reef, in the gun-boat, gave always a coral-sand containing:—Broken pieces of coral; Polyzoa, *Serpula*, large Foraminifera, *Textularia*, *Nodosaria*, Crystellarias, &c.; broken pieces of Echinoderm shells &c.

Sounding 71. 21st April, 1873. 1375 fathoms. A coral-mud, same as No. 69. Specimen not preserved.

Sounding 72. 22nd April, 1873. 2450 fathoms. Lat. 32° 39′ N., long. 65° 6′ W. A coral-mud containing:—Much amorphous calcareous and a little clayey matter; many pelagic Foraminifera and Coccoliths; a few siliceous spines; a few mineral particles, some green, some of an olive-colour (serpentine and olivine ?).

Sounding 73. 22nd April, 1873. 2100 fathoms. Lat. 32° 26′ N., long. 65° 9′ W. A coral-mud containing:—Many pelagic Foraminifera, Pteropods, other surface shells, Coccoliths, and Rhabdoliths; broken pieces of Coral, Polyzoa, and shore forms of Foraminifera; a few siliceous spines and Radiolaria.

Sounding 74. 22nd April, 1873. 1950 fathoms. Lat. 32° 15′ N., long. 65° 8′ W. Same as last, with more pelagic shells and larger pieces of broken coral.

23rd April, 1873. 32 fathoms. About 13 miles S.W. of Bermuda. A hard bottom composed chiefly of large pieces of broken *Serpula* reefs, on which were *Crystellaria* and other large Foraminifera, Alcyonarians, &c.

Sounding 75. 24th April, 1873. 2650 fathoms. Lat. 32° 19′ N., long. 65° 39′ W. A coral-mud containing:—Many pelagic and other Foraminifera and their broken parts; many Coccoliths and Rhabdoliths; amorphous, calcareous, and some clayey matter; a few mineral particles, white and yellow (mica); a few siliceous spines and Radiolaria.

Sounding 76. 25th April, 1873. 2600 fathoms. Lat. 33° 3′ N., long. 66° 32′ W. A grey clay containing:—Much amorphous clayey matter; many fine mineral particles, some of a yellow colour, others white; a good many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few manganese grains.

Sounding 77. 27th April, 1873. 2850 fathoms. Lat. 34° 3′ N., long. 67° 32′ W. A red clay containing:—Much amorphous clayey matter; many very fine and some rather coarse mineral particles—mica, quartz, olivine (?), &c.; a good many pelagic Foraminifera and some Coccoliths.

Sounding 78. 28th April, 1873. 2675 fathoms. Lat. 34° 51′ N., long. 68° 30′ W. A small quantity of mud came up in the dredge which indicated a bottom same as the last.

Sounding 79. 30th April, 1873. 2425 fathoms. Lat. 35° 58′ N., long. 70° 39′ W. A blue mud with reddish upper layer containing:—Much amorphous clayey matter; many fine and coarse mineral particles, as quartz, mica, &c., and a green and red mineral; a good many pelagic Foraminifera and Coccoliths; a few Radiolaria and Diatoms (*Coccinodiscus* &c.).

Sounding 81. 2nd May, 1873. 1700 fathoms. Lat. 37° 25′ N., long. 71° 40′ W. A blue mud containing:—Much amorphous clayey matter; many fine and coarse mineral particles, as quartz, mica, &c.; a good many pelagic Foraminifera and Coccoliths; a good many Diatom remains and a few Radiolaria.

Sounding 82. 3rd May, 1873. 1240 fathoms. Lat. 38° 34′ N., long. 72° 10′ W. A blue mud containing:—Amorphous clayey matter; many coarse mineral particles as quartz, mica, granitic pebbles, &c.; a few pelagic and other Foraminifera, Coccoliths; a good many Diatom remains.

Sounding 83. 6th May, 1873. 1350 fathoms. Lat. 40° 17′ N., long. 66° 48′ W. A blue mud, same as the last.

Sounding 84. 7th May, 1873. 1340 fathoms. Lat. 41° 15′ N., long. 65° 45′ W. A blue mud comprised of:—Amorphous matter; an immense number of mineral particles and pebbles; pelagic Foraminifera and Coccoliths; a few Diatoms; a few glauconitic casts of the Foraminifera were noticed after treatment with acid; a block of cyanite (5 cwt.) came up in the dredge.

8th and 20th May, 1873. 75 and 83 fathoms. Lat. 43° 2′ N., long. 64° 2′ W., and lat. 43° 3′ N., long. 63° 39′ W. Le Havebank. The bottom was composed of sand and gravel. Two or three Foraminifera and glauconitic casts.

Sounding 85. 21st May, 1873. 1250 fathoms. Lat. 42° 8′ N., long. 63° 31′ W. A blue mud containing:—Amorphous matter; very many sandy particles (quartz, mica, &c.); a good many pelagic and other Foraminifera; Coccoliths and Rhabdoliths; a few Diatoms and Radiolarian remains.

Sounding 86. 22nd May, 1873. 2020 fathoms. Lat. 41° 19′ N., long. 63° 12′ W. A blue mud, with red upper layer, containing:—Amorphous clayey matter; a great many mineral particles, as mica, quartz, &c.; many pelagic Foraminifera and Coccoliths; a few Radiolaria and Diatoms.

Sounding 87. 23rd May, 1873. 2800 fathoms. Lat. 39° 44′ N., long. 63° 22′ W. A red or grey clay containing:—Much amorphous clayey matter; very many fine mineral particles, and a few rather coarse ones of mica, quartz, and a green mineral; a good many pelagic Foraminifera and Coccoliths.

Sounding 88. 26th May, 1873. 2650 fathoms. Lat. 36° 30′ N., long. 63° 40′ W. A red or grey clay containing:—Much amorphous clayey matter; very many fine and a few rather coarse mineral particles—quartz, mica, and a green mineral (serpentine ?); a good many pelagic Foraminifera, Coccoliths, and Rhabdoliths.

Sounding 89. 27th May, 1873. 2650 fathoms. Lat. 34° 50′ N., long. 63° 59′ W. A red clay containing:—Much amorphous clayey matter; many very fine mineral particles; a good many pelagic Foraminifera and their broken parts; Coccoliths and Rhabdoliths.

Sounding 90. 27th May, 1873. 2500 fathoms. Lat. 33° 20′ N., long. 64° 37′ W. A red clay, much the same as the last, but containing perhaps rather more carbonate-of-lime organisms.

Sounding 92. 29th May, 1873. 1325 fathoms. A coral-mud containing:—Much amorphous calcareous matter; pelagic Foraminifera, Pteropod and Heteropod shells; Coccoliths and Rhabdoliths; broken pieces of coral, Polyzoa, &c.; a few siliceous spines and Radiolaria.

Sounding 93. 29th May, 1873. 1075 fathoms. A coral-mud, much the same as the above, but having a few white and green mineral particles.

Sounding 94. 30th May, 1873. 1250 fathoms. A coral-mud containing:—Much amorphous calcareous matter; many pelagic Foraminifera, Pteropods, Heteropods, Coccoliths, and Rhabdoliths; a few siliceous spines and Radiolaria; some white and green mineral particles (mica).

Sounding 95. 30th May, 1873. 1575 fathoms. A coral-mud containing:—Many pelagic and other Foraminifera, Pteropods, Heteropods, and surface Gasteropods, Coccoliths, and Rhabdoliths; amorphous calcareous matter; a few siliceous spines; a few quartz and other mineral particles.

Sounding 96. 13th June, 1873. 1500 fathoms. Lat. 32° 37′ N., long. 64° 21′ W. A coral-mud containing:—Many pelagic and other Foraminifera, Pteropods, and Heteropods; Coccoliths and Rhabdoliths; much amorphous calcareous matter; a few Radiolaria and siliceous spines; a few green mineral particles.

Sounding 97. 14th June, 1873. 2360 fathoms. Lat. 32° 54′ N., long. 63° 22′ W. A grey clay containing:—Much amorphous clayey and calcareous matter; a good many exceedingly fine mineral particles; a good many pelagic Foraminifera and Coccoliths; one or two Radiolarians.

Sounding 98. 16th June, 1873. 2575 fathoms. Lat. 34° 28′ N., long. 58° 56′ W. A red clay containing:—Much amorphous clayey matter; many fine mineral particles, and a few rather coarse ones; a good many pelagic Foraminifera and their broken-down parts; one or two grains of manganese.

Sounding 99. 17th June, 1873. 2850 fathoms. Lat. 34° 54′ N., long. 56° 38′ W. A red clay containing:—Amorphous clayey matter;

very many sandy particles, as quartz, mica, red and green minerals; the green mineral (glauconite) appears the same as those particles in the bottoms where the green casts of the Foraminifera occur; a good many pelagic Foraminifera and a few Coccoliths; one or two manganese grains.

The dredge brought up several concretions, coated on the outside with the black oxide of manganese. To one of these a *Scalpellum* was attached.

Sounding 100. 18th June, 1873. 2875 fathoms. Lat. 35° 7′ N., long. 52° 32′ W. A red clay containing:—Amorphous matter; very many fine and a few rather coarse mineral particles, as mica, quartz, pieces of a green and a red mineral, all much smaller than yesterday; a few pelagic Foraminifera and their broken parts; a few Coccoliths.

Sounding 101. 19th June, 1873. 2750 fathoms. Lat. 35° 29′ N., long. 50° 53′ W. A grey clay containing:—Much amorphous clayey matter; many very fine mineral particles; many pelagic Foraminifera and their broken parts, and Coccoliths; one or two Radiolaria.

Is lighter in colour and contains more carbonate of lime than yesterday.

Station 64. 20th June. 2750 fathoms. Lat. 35° 35′ N., long. 50° 27′ W.

Sounding 102. 21st June. 2700 fathoms. Lat. 36° 33′ N., long. 47° 58′ W.

Sounding 103. 22nd June. 2750 fathoms. Lat. 37° 24′ N., long. 44° 14′ W.

Sounding 104. 23rd June. 2700 fathoms. Lat. 37° 54′ N., long. 41° 44′ W.

All a grey clay, same as No. 101.

In the dredge on the 20th there were a few manganese pellets.

Sounding 105. 24th June, 1873. 2175 fathoms. Lat. 38° 3′ N., long. 39° 19′ W. A *Globigerina*-ooze of reddish colour containing:—Great numbers of pelagic Foraminifera, Coccoliths, and Rhabdoliths; some amorphous clayey matter of a red colour; a few Radiolarians.

Sounding 106. 25th June, 1873. 2200 fathoms. Lat. 38° 23′ N., long. 37° 21′ W. A small quantity came up which indicated a *Globigerina*-ooze of a rather lighter colour than yesterday.

Sounding 107. 26th June, 1873. 1675 fathoms. Lat. 38° 25′ N., long. 35° 50′ W. A *Globigerina*-ooze containing:—Great numbers of pelagic Foraminifera, Coccoliths, and Rhabdoliths; *Cypridina*-valves; a few Radiolaria (many more than usually); a few fine and coarse mineral particles.

Sounding 108. 27th June, 1873. 1675 fathoms. Lat. 38° 18′ N., long.

34° 48′ W. A *Globigerina*-ooze (same as yesterday); a few grey-coloured concretions in the trawl.

Sounding 109. 28th June, 1873. 1240 fathoms. Lat. 38° 34′ N., long. 32° 47′ W. A *Globigerina*-ooze containing:—Great numbers of pelagic Foraminifera, Coccoliths, and Rhabdoliths; otoliths of fish; *Cypridina*-valves; *Echini*-spines; *Biloculina* and other Foraminifera; a few Radiolaria; many mineral particles, red, white, and black; volcanic sand.

Sounding 110. 30th June, 1873. 1000 fathoms. Lat. 38° 30′ N., long. 31° 14′ W. A *Globigerina*-ooze containing:—Many pelagic Foraminifera; Pteropods, Heteropods, and other surface shells; otoliths of fish, *Cypridina*-valves, *Echini*-spines, &c.; a few Radiolaria; a good many mineral particles, chiefly volcanic sand and pumice.

Sounding 111. 1st July, 1873. 1350 fathoms. Lat. 38° 22′ N., long. 29° 37′ W. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; amorphous calcareous matter; a good many Radiolarian and siliceous spines; many fine mineral particles, chiefly pumice and grains of volcanic sand.

Sounding between Fayal and Pico. 450 fathoms. 8 miles N.E. of Aorta. A grey mud containing:—Many mineral particles, as pumice, volcanic sandy particles (mica); many pelagic and other Foraminifera; Pteropods, Heteropods, surface Gasteropods, and small laval Lamellibranchs; a few siliceous spines.

Sounding 112. 3rd July, 1873. 900 fathoms. Lat. 38° 11′ N., long. 27° 9′ W. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera; broken Pteropod shells, Coccoliths, and Rhabdoliths, &c.; a great deal of volcanic sand and disintegrating pumice; a few Radiolarians and siliceous spines.

Sounding 114. 10th July, 1873. 1000 fathoms. Off San Miguel Island. A grey mud containing:—Many fine and large particles of pumice, and black, red, and white particles of volcanic sand; some pelagic Foraminifera, Pteropods, and other surface shells.

Sounding 115. 11th July, 1873. 2025 fathoms. Lat. 36° 21′ N., long. 23° 31′ W. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths and Rhabdoliths; a good deal of pumice and volcanic sand (mica); a few Radiolarians.

Sounding 116. 12th July, 1873. 2660 fathoms. Lat. 35° 3′ N., long. 21° 25′ W. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera and their broken parts; a few Coccoliths and Rhabdoliths; a good deal of amorphous calcareous matter; a good many mineral particles, pumice, quartz, mica, &c.; a few Radiolarians.

Sounding 117. 13th July, 1873. 2675 fathoms. Lat. 34° 11′ N., long. 19° 52′ W. A white *Globigerina*-ooze containing:—Much amorphous calcareous matter; many pelagic Foraminifera and their broken parts; Coccoliths and Rhabdoliths; a good many mineral particles, coarse and fine pumice, quartz, mica; a few Radiolarians.

Sounding 118. 14th July, 1873. 2400 fathoms. Lat. 33° 46′ N., long. 19° 17′ W. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera and their broken parts; Coccoliths and Rhabdoliths; amorphous calcareous matter; some fine and coarse black and white mineral particles; a few Radiolaria.

Sounding 119. 15th July, 1873. 1650 fathoms. Lat. 33° 13′ N., long. 18° 13′ W. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; a good deal of fine volcanic sandy particles of a white, red, and black colour; a few Radiolaria.

Sounding 120. 19th July, 1873. 1125 fathoms. Lat. 28° 42′ N., long. 18° 6′ W. A brown or grey mud containing:—A large quantity of volcanic sand, the majority of the particles being black and brown; a few pelagic Foraminifera, Pteropods, Coccoliths, and Rhabdoliths; one or two Radiolaria. The dredge brought up some pieces of a dead Gorgonoid, with a coating of manganese.

Sounding 121. 21st July, 1873. 2300 fathoms. Lat. 25° 46′ N., long. 20° 34′ W. A *Globigerina*-ooze with a red tinge containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths, and amorphous calcareous matter; a good deal of mineral matter of a white, red, and yellow colour, and a few grains of manganese.

Sounding 122. 21st July, 1873. 1675 fathoms. Lat. 25° 49′ N., long. 20° 12′ W. Four miles to the north of sounding No. 39. Three small pieces of a dead Gorgonoid covered with manganese came up.

Sounding 123. 22nd July, 1873. 2300 fathoms. Lat. 23° 58′ N., long. 21° 18′ W. A *Globigerina*-ooze with a red tinge containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths; a good many red, white, and yellow mineral particles; a few manganese grains; one or two Radiolaria.

Sounding 124. 23rd July. 2400 fathoms. Lat. 22° 18′ N., long. 22° 2′ W.

Sounding 125. 24th July. 2400 fathoms. Lat. 20° 58′ N., long. 22° 57′ W.

Sounding 126. 25th July. 2075 fathoms. Lat. 19° 4′ N., long. 24° 6′ W.

Sounding 127. 26th July. 1975 fathoms. Lat. 17° 54′ N., long. 24° 41′ W.

All gave a *Globigerina*-ooze with a red tinge, and in other respects the same as No. 123.

Sounding 128. 27th July, 1873. 1070 fathoms. Off San Antonio. A dark brown or grey mud containing:—Very many particles of volcanic sand of a red, white, yellow, and black colour.

Sounding 129. 27th July, 1873. 1000 fathoms. Off St. Vincent. A bark brown or grey mud containing:—Much volcanic sand; pelagic Foraminifera and broken pieces of Pteropod; Coccoliths and Rhabdoliths; a few siliceous spines.

Sounding 130. 27th July, 1873. 465 fathoms. Off St. Vincent. A dark brown or grey mud containing:—Much coarse volcanic sand; a few pelagic and other Foraminifera; a few Coccoliths; broken pieces of coral, Polyzoa, &c.

Sounding 130 A. 27th July, 1873. 52 fathoms. Off St. Vincent. A coarse coral-sand, composed of:—Broken pieces of corallines, corals, Polyzoa, large Nummulinas and other Foraminifera, and a few pelagic Foraminifera, and Pteropods.

5th August, 1873. Off St. Vincent. 260 fathoms. A green sand, composed chiefly of:—Green, red, and black mineral particles; pelagic and other Foraminifera; broken pieces of Pteropods, Heteropods, Polyzoa, Coralline, &c.; one or two pale imperfect casts of the Pteropods.

5th August, 1873. Off St. Vincent. 675 fathoms. A grey mud containing:—Much volcanic sand; pelagic Foraminifera, Heteropods, Pteropods, and other surface shells; Coccoliths and Rhabdoliths.

Sounding 131. 5th August, 1873. 1150 fathoms. Off St. Vincent. A grey *Globigerina*-ooze containing:—Very many pelagic Foraminifera; shells of Pteropods, Heteropods, larval Gasteropods, and Lamellibranchs; a good many particles of volcanic sand, of a red, white, and green colour; a few siliceous spines.

St. Vincent to Bahia.

Sounding 132. 10th August, 1873. 2300 fathoms. Lat. 13° 36′ N., long. 22° 49′ W. A *Globigerina*-ooze of reddish tinge containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; some amorphous clayey matter, and many fine mineral particles; a few Radiolarians.

Sounding 133. 13th August, 1873. 2575 fathoms. Lat. 10° 25′ N., long. 20° 30′ W. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera and a few Coccoliths; a good deal of amorphous clayey matter, and many very fine mineral particles; a few Radiolarians.

Sounding 134. 14th August, 1873. 1750 fathoms. Lat. 9° 21′ N., long. 18° 28′ W. A blue mud containing:—Much amorphous clayey matter; a good many fine mineral particles; a good many pelagic Foraminifera and Coccoliths; a few Radiolaria.

Sounding 136. 19th August, 1873. 2500 fathoms. Lat. 5° 48′ N., long. 14° 20′ W. A dark blue mud containing:—Much amorphous clayey matter; many fine mineral particles; a few pelagic Foraminifera and their broken parts.

Sounding 137. 21st August, 1873. 2450 fathoms. Lat. 3° 8′ N., long. 14° 49′ W. A grey *Globigerina*-ooze containing:—Very many pelagic Foraminifera and Coccoliths; much amorphous clayey matter and fine mineral particles; a good many Radiolaria.

Sounding 138. 22nd August, 1873. 2475 fathoms. Lat. 2° 49′ N., long. 17° 13′ W. Some patches of a grey ooze came up on the outside of the tube.

Sounding 139. 23rd August, 1873. 2500 fathoms. Lat. 2° 25′ N., long. 20° 1′ W. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera and a few Coccoliths; much amorphous clayey matter, and many fine white and red mineral particles; a few manganese grains.

Sounding 140. 24th August, 1873. 2275 fathoms. Lat. 2° 6′ N., long. 22° 53′ W. Some traces of a grey ooze came up on the outside of the sounding-tube.

Sounding 141. 25th August, 1873. 1850 fathoms. Lat. 1° 47′ N., long. 24° 26′ W. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera; many Coccoliths and Rhabdoliths; a little amorphous clayey and calcareous matter; a few white and red mineral particles; small manganese grains attached to many of the Foraminifera.

Sounding 142. 26th August, 1873. 1500 fathoms. Lat. 1° 22′ N., long. 26° 36′ W. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few broken pieces of Pteropod shells; a little amorphous clayey matter and some fine mineral particles; one small piece of pumicestone.

Sounding 143. 27th August, 1873. 1900 fathoms. Lat. 1° 10′ N., long. 28° 23′. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera; Coccoliths; a good many Radiolarians; a little amorphous clayey matter, and a few white mineral particles.

Sounding 144. 29th August, 1873. 1425 fathoms. Off St. Paul's Rocks. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera:—a few Pteropod shells; Coccoliths; a good many mineral particles, mica, serpentine, &c.; one or two Radiolarians.

Off St. Paul's Rocks. 29th August, 1873. 780 fathoms. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera and Coccoliths; a few Pteropod, Heteropod, and pelagic Gasteropod shells; many rough crystalline particles, of a green, black, red, and white colour.

Sounding 145. 30th August, 1873. 2275 fathoms. Lat. 0° 9′ N., long. 30° 18′ W. A *Globigerina*-ooze with reddish tinge containing:—Many pelagic Foraminifera; Coccoliths; some amorphous calcareous and clayey matter; a good many Radiolarians; a few fine crystalline particles.

Sounding 146. 31st August, 1873. 2475 fathoms. Lat. 1° 45′ S., long. 30° 58′ W. A *Globigerina*-ooze of a red colour containing:—many pelagic Foraminifera and their broken parts; a few Coccoliths; much amorphous clayey matter; many very fine mineral particles; one or two Radiolaria.

About one half of this specimen was clayey, the other calcareous.

Sounding 147. 1st September, 1873. 2200 fathoms. Lat. 3° 33′ S., long. 32° 16′ W. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths; some red amorphous matter, and some red and white mineral particles.

Sounding 148. No bottom came up. 1010 fathoms. Off Fernando Noronha.

Sounding 149. No bottom came up. 820 fathoms. Lat. 3° 58′ S., long. 32° 42′ W.

Sounding 150. 3rd September, 1873. 2150 fathoms. Lat. 4° 2′ S., long. 32° 47′ W. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths; a few white and red mineral particles; a few Radiolaria.

Sounding 151. 4th September, 1873. 2275 fathoms. Lat. 5° 1′ S., long. 33° 50′ W. A *Globigerina*-ooze with a red tinge containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths; amorphous matter and many fine white mineral particles; one or two Radiolaria and siliceous spicules.

Sounding 152. 6th September, 1873. 1375 fathoms. Lat. 5° 56′ S., long. 34° 45′ W. A red or yellow mud containing:—Much amorphous clayey matter; many fine white and red mineral particles; many pelagic Foraminifera, broken pieces of Pteropods and pelagic Gasteropods; Coccoliths and Rhabdoliths.

Sounding 152A. 6th September, 1873. 500 fathoms. Off Brazilian coast. A red mud containing:—Much amorphous matter; many mineral particles, quartz and mica; a good many pelagic Foraminifera; surface Gasteropods, Heteropods, and a few Coccoliths and Rhabdoliths.

Sounding 153. 8th September, 1873. 2050 fathoms. Lat. 7° 28′ S., long. 34° 2′ W. A red or yellow mud containing:—Much amorphous clayey matter of a red colour; many coarse and fine mineral particles, chiefly quartz and mica; a good many pelagic Foraminifera; Coccoliths and Rhabdoliths; a few siliceous spicules, but no Radiolaria observed.

			fathoms.		° ′		° ′
Sounding	154.	8th Sept., 1873.	1650.	Lat.	7 39 S.,	long.	34 12 W.
„	155.	9th „	675.	„	8 37 S.,	„	34 28 W.
„	156.	9th „	500.	„	8 28 S.,	„	34 31 W.
„	157.	10th „	350.	„	9 5 S.,	„	34 50 W.
„	A.	10th „	120.	„	9 10 S.,	„	34 52 W.
„	B.	10th „	32.	„	9 9 S.,	„	34 53 W.
„	C.	10th „	400.	„	9 10 S.,	„	34 49 W.
„	158.	11th „	1715.	„	10 9 S.,	„	35 11 W.
„	159.	11th „	1600.	„	10 11 S.,	„	35 22 W.
„	160.	12th „	1200.	„	10 46 S.,	„	36 2 W.
„	161.	12th „	700.	„	10 45 S.,	„	36 9½ W.
„	162.	13th „	1015.	„	11 42 S.,	„	37 3 W.
„	163.	14th „	1275.	„	13 6 S.,	„	38 7 W.

All these soundings along the coast of South America, from Cape San Roque to Bahia, gave a red or yellow mud as described under soundings 152 and 153. Those in the shallower depths were of a redder colour and contained larger mineral particles and fewer pelagic organisms than those in deeper water and further from the coast. Remains of siliceous organisms were almost entirely absent. In No. 157 A, 120 fathoms, there were a few red-coloured internal casts of Foraminifera.

Bahia to Cape of Good Hope.

Sounding 164. 30th September, 1873. 2150 fathoms. Lat. 20° 13′ S., long. 35° 19′ W. A red mud containing:—Much amorphous clayey matter; many fine mineral particles, mica, quartz, &c.; many pelagic Foraminifera; Coccoliths and Rhabdoliths; a few manganese grains; no siliceous things noticed.

Sounding 165. 3rd October, 1873. 2350 fathoms. Lat. 26° 15′ S., long. 32° 56′ W. A red or grey clay containing:—Much amorphous clayey matter; a few rather large and many very small white mineral particles; a good many remains of pelagic Foraminifera; a few Coccoliths and Rhabdoliths; a few small manganese pellets.

Sounding 166. 6th October, 1873. 2275 fathoms. Lat. 29° 35′ S., long. 28° 9′ W. A grey clay containing:—Much amorphous clayey matter and some amorphous calcareous matter; a few rather large and many very small mineral particles, quartz, pumice, &c.; a good many pelagic Foraminifera; Coccoliths and Rhabdoliths; one or two pieces of Diatoms; a few manganese grains.

The dredge brought up an ear-bone of a Cetâcean and a piece of pumice, both coated with the peroxide of manganese.

Sounding 167. 10th October, 1873. 2050 fathoms. Lat. 35° 25′ N., long. 23° 40′ W. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; a little amorphous calcareous and clayey matter; a good many Radiolaria; a few yellow, red, and white mineral particles.

Sounding 168. 11th October, 1873. 1900 fathoms. Lat. 35° 41′ S., long. 20° 55′ W. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; a little amorphous calcareous and clayey matter; a few Radiolarians and siliceous spines; a few coarse and fine mineral particles.

Sounding 169. 14th October, 1873. 2025 fathoms. Lat. 36° 12′ S., long. 12° 16′ W. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera; Coccoliths and Rhabdoliths; some amorphous clayey and calcareous matter; many sandy particles, of a red, white, and black colour; a good many Radiolaria.

Off Tristan d'Acunha. 15th October, 1873. 360 fathoms. A dark grey mud containing:—Much volcanic sand of a black and red colour (olivine &c.); a few pelagic Foraminifera, Pteropods, surface Gasteropods, &c.

Sounding 170. 18th October, 1873. 1100 fathoms. Off Tristan d'Acunha. A piece of shell came up in the tube. In the dredge were several lumps of pumice.

Sounding 172. 20th October, 1873. 2100 fathoms. Lat. 36° 43′ S., long. 7° 13′ W. No bottom came up.

Sounding 173. 23rd October, 1873. 2550 fathoms. Lat. 35° 59′ S., long. 1° 34′ E. A red clay containing:—Much amorphous clayey matter; a few rather coarse and many very fine mineral particles; a few broken remains of pelagic Foraminifera and a few Coccoliths; a few Radiolarians; a few manganese grains.

Sounding 174. 25th October, 1873. 2650 fathoms. Lat. 36° 22′ S., long. 8° 12′ E. A red clay containing:—Much amorphous clayey matter; very many coarse and fine white mineral particles (quartz and pumice); a good many broken remains of pelagic Foraminifera; a few Radiolarians; a small tooth of shark; a few pellets of black manganese.

Sounding 175. 27th October, 1873. 2325 fathoms. Lat. 35° 35′ S., long. 16° 8′ E. A blue mud containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; very many mineral particles, mostly of a white colour (quartz), but also many dark and light green coloured (glauconite); a few Radiolarians and siliceous spines; a few pellets of manganese.

Sounding 176. 28th October, 1873. 1250 fathoms. Lat. 35° 0′ S., long. 17° 57′ E. A blue mud containing:—Much amorphous clayey matter; very many sandy particles, quartz and green glauconite grains; a good many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few Radiolaria and siliceous spines.

SOUTHERN OCEAN.

Cape of Good Hope to Australia.

Simon's Bay. 20 fathoms. Dredges gave a bottom composed of sandy particles, quartz and green and black particles, pieces of broken shells, Echinoderm shells, Foraminifera, &c.; mixed up with these was much amorphous matter, which gave a green colour to the bottom.

Sounding 177. 17th December, 1873. 100 fathoms. Lat. 34° 41′ S., long. 18° 36′ E. A green mud containing:—Very many small light and dark green mineral particles, usually of a rounded form, and quartz, mica, &c.; a good many pelagic Foraminifera; other Foraminifera, as Textularias, Rotalias, Uvigerinas, Nummulinas, &c.; a few siliceous spines and Diatoms; green-coloured amorphous matter; many casts of the Foraminifera, *Echini*-spines, and other carbonate-of-lime organisms in pale green substance (glauconite).

18th December, 1873. 150 fathoms. Agulhas Bank. Lat. 35° 4′ S., long. 18° 37′ E. Same kind of bottom as No. 177.

Sounding 178. 19th December, 1873. 1900 fathoms. Lat. 36° 48′ S., long. 19° 24′ E. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera and Coccoliths; a great many mineral particles, quartz, and a red and green mineral; one or two parts of siliceous spines, but no Radiolarians: a few casts of the Foraminifera remained after treatment with acid; some of these were pure white, others had a greenish tinge.

The dredge brought up some stones of a black colour. These were very hard, and made up of *Globigerina* and small green and white particles imbedded in a grey flinty-like matrix. Internal casts of the Foraminifera in this flinty-like substance remained when portions of these concretions were treated with acid. The black colour was due to a thin coating of the peroxide of manganese.

Sounding 179. 24th December, 1873. 1570 fathoms. Lat. 45° 57′ S., long. 34° 39′ E. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera and Coccoliths; a few Radiolarians and Diatoms; a few white, red, and green mineral particles, some of them rather large.

26th and 27th December, 1873. 50 to 150 fathoms. Off Prince-Edward Island. The dredges in these depths gave a black or dark-grey sand containing:—Many black or brown mineral particles; pieces of broken shells; Polyzoa; Echinoderms; some pelagic and other Foraminifera.

Sounding 180. 29th December, 1873. 1375 fathoms. Lat. 46° 46′ S., long. 45° 31′ E. A white *Globigerina*-ooze containing:—Many pelagic Foraminifera and a few Coccoliths; many Radiolarian and Diatom remains; a few mineral particles of a white and green colour.

The fine parts of the sounding were nearly all Diatom remains.

Sounding 181. 30th December, 1873. 1600 fathoms. Lat. 46° 16′ S., long. 48° 27′ E. A grey *Globigerina*-ooze containing:—Many pelagic Foraminifera (Coccoliths and Pulvinulinas appeared wholly absent); many Diatoms and Radiolaria; many white, black, and red mineral particles.

The finer portions appeared wholly made up of the broken frustules of Diatoms.

Sounding 182. 1st January, 1874. 600 fathoms. Off the Crozet Islands. A grey mud containing:—Many pelagic Foraminifera; Globigerinas (Orbulinas, Pulvinulinas, and Coccoliths appeared to be quite absent); very many remains of Diatoms and Radiolaria; many black, yellow, and red sandy particles.

Beautiful casts of the *Echini*-spines and Foraminifera remained after treatment with acid. These were of a pale straw-colour (green glauconitic particles were not observed in this sounding).

January 1874. 20 to 100 fathoms. During this month many soundings were taken off the east coast of Kerguelen Land in from 20 to 100 fathoms. The tube always brought up grey or blue mud containing:—Very many sandy particles of white, red, and black colour; many Diatoms and spicules of sponges.

The soundings furthest from the coast were mostly a network of sponge-spicules and frustules of Diatoms.

2nd February, 1874. 150 fathoms. Between Kerguelen and Heard Islands. The bag of the trawl came up with many basaltic and other pebbles, to which many Brachiopods were attached and some frustules of Diatoms adhered.

7th February, 1874. 75 fathoms. Off Heard Island. The bottom was a grey sandy mud containing many black sandy particles, sponge-spicules, Diatoms, &c., as off Kerguelen.

Sounding 184. 11th February, 1874. 1260 fathoms. Lat. 60° 52′ S., long. 80° 20′ E. A diatomaceous ooze of pure white colour containing:—Chiefly frustules of Diatoms and their broken-down parts; many Radiolaria; a few *Globigerina*; a few white, black, and red mineral particles (mica).

Sounding 185. 14th February, 1874. 1675 fathoms. Lat. 65° 42′ S., long. 79° 48′ E. A blue mud (greenish tinge) containing:—Much amorphous clayey matter; a great many white, black, and yellow sandy particles (quartz &c.); some granitic pebbles; a good many frustules of Diatoms amongst the amorphous matter; a few Radiolaria; two small *Globigerina* were noticed in the portion examined. The mud did not effervesce with acid.

Sounding 186. 19th February, 1874. 1800 fathoms. Lat. 64° 37′ S., long. 85° 49′ E. A blue mud containing:—Much amorphous clayey matter; some coarse and a very great number of very fine mineral particles, as quartz, mica, and black and yellow particles; a good many frustules of Diatoms and a few Radiolaria; one or two small *Globigerina.*

The above two soundings are in many respects like those we usually got when approaching a continent or large island, especially like those soundings off the coast of North America at 80 to 100 miles from the coast.

Sounding 187. 23rd February, 1874. 1300 fathoms. Lat. 54° 18′ S., long. 94° 47′ E. A yellowish-blue mud containing:—Much amorphous matter; many coarse and fine mineral particles, quartz, mica, and red and yellow particles; many remains of Diatoms and Radiolaria; a good many pelagic Foraminifera (small *Globigerina* only); might be called a Diatom-ooze.

Sounding 188. 26th February, 1874. 1975 fathoms. Lat. 62° 36′ S., long. 95° 44′ E. A diatomaceous ooze containing chiefly (of a yellow colour):—The frustules of Diatoms and their broken-down parts; many Radiolaria; no pelagic Foraminifera in the portion examined; a few quartz, mica, and other mineral particles; a few granitic pebbles came up in the trawl.

Sounding 189. 3rd March, 1874. 1950 fathoms. Lat. 53° 55′ S., long. 108° 35′ E. A diatomaceous ooze of a straw-colour containing chiefly:—The frustules of Diatoms and their broken-down parts; many Radiolaria; a few small *Globigerina*; one or two quartz and mica particles.

Sounding 190. 7th March, 1874. 1800 fathoms. Lat. 50° 1′ S., long. 123° 4′ E. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera (*Globigerina,* Pulvinulinas, and a few Orbulinas); Coccoliths; a good many Diatoms and Radiolaria; one or two quartz particles and one or two pieces of a cherty-like mineral.

Sounding 191. 10th March, 1874. 2150 fathoms. Lat. 47° 25′ S., long. 130° 32′ E. A *Globigerina*-ooze, with a red tinge, containing:—Very fine pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few Diatoms and Radiolaria; one or two small white mineral particles, and one or two red and black manganese grains.

Sounding 192. 13th March, 1874. 2600 fathoms. A red clay containing:—Much amorphous clayey matter; many very fine white mineral particles and a few black obsidian-like particles and manganese grains; a few whole and many broken pieces of pelagic Foraminifera and a few Coccoliths; two Radiolarians noticed; no Diatoms.

The trawl brought up many round manganese concretions or nodules, and one or two shark's teeth.

Melbourne to Sydney.

Sounding 193. 4th April, 1874. 2200 fathoms. Lat. 36° 56′ S., long. 150° 30′ E. A green mud containing:—Amorphous clayey matter; many fine mineral particles, quartz, mica, and green glauconite particles, &c.; a good many pelagic Foraminifera and Coccoliths; a few broken pieces of Pteropod shells; a few remains of Diatoms and siliceous spines.

Sydney to Wellington.

12th June, 1874. Off Port Jackson. 120, 290, and 650 fathoms. Soundings at these depths gave a greenish mud containing:—Many coarse sandy particles; quartz, mica, and glauconite particles; many pelagic and other Foraminifera; broken pieces of Pteropod and other surface shells, Echinoderm spines, &c.

In the shallower soundings there were great numbers of green casts of the Foraminifera and other shells.

Sounding 194. 24th June, 1874. 950 fathoms. Lat. 34° 8′ S., long. 152° 0′ E. A green mud containing:—Many fine and coarse mineral particles, quartz, mica, green and red minerals; many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few siliceous spines; many pale white casts of the Foraminifera remained after treatment with acid.

Sounding 195. 13th June, 1874. 1200 fathoms. Lat. 34° 9′ S., long. 151° 55′ E. A greenish mud containing:—Very many fine and some coarse mineral particles, quartz, mica, green and red minerals; very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few pieces of siliceous spines.

A few white casts of Foraminifera remained after treatment with acid.

Sounding 196. 13th June, 1874. 400 fathoms. Lat. 34° 19′ S., long. 151° 31′ E. A green mud containing:—Very many sandy particles;

quartz, mica, glauconite, and red and black minerals; many pelagic and other Foraminifera, Coccoliths, and Rhabdoliths; a few siliceous spines.

Beautiful and wonderfully perfect casts of the carbonate-of-lime organisms remained after treatment with acid, as *Echini*-spines, Polyzoa, and Foraminifera, &c. Some of these were dark green, some pale green, and others a dirty white colour.

Compare 600 fathoms, off Crozets.

Soundings 197 and 198. Lines parted.

Sounding 199. 17th June, 1874. 2600 fathoms. Lat. 34° 50′ S., long. 155° 28′ E. A red clay containing:—Amorphous clayey matter; many exceedingly fine mineral particles, quartz, mica, red and green particles (pumice?); a good many broken pieces of pelagic Foraminifera and a few Coccoliths; one or two pieces of siliceous spines; one or two manganese grains.

Sounding 200. 19th June, 1874. 2600 fathoms. Lat. 36° 41′ S., long. 158° 29′ E. A red clay containing:—Amorphous clayey matter; many very fine mineral particles of a white and black colour; a few broken pieces of pelagic Foraminifera; a few broken parts of Radiolaria; a few manganese grains.

Sounding 201. 21st June, 1874. 1975 fathoms. Lat. 37° 53′ S., long. 163° 18′ E. A white *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; much amorphous calcareous and some clayey matter; a good many Radiolaria; one or two black and small white mineral particles (scoria and pumice?).

Sounding 202. 22nd June, 1874. 1100 fathoms. Lat. 38° 36′ S., long. 166° 39′ E. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; some amorphous calcareous matter; a good many Radiolarians and some Diatom remains; one or two small green and red mineral particles.

There were one or two nearly pure white casts of Foraminifera.

Sounding 203. 23rd June, 1874. 275 fathoms. Lat. 38° 50′ S., long. 169° 20′ E. A small quantity which came up indicated *Globigerina*-ooze, containing:—Many pelagic and other Foraminifera; many Coccoliths, Rhabdoliths, and *Echini*-spines.

The trawl brought up many Globigerinas, Pulvinulinas, Orbulinas, and other Foraminifera, *Echini*-spines, surface-shells, &c. All the finer portions of the bottom had been washed out of the bag.

23rd June, 1874. 400 fathoms. A *Globigerina*-ooze containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths (the Coccoliths were very large and numerous, and made up perhaps 15 cwt. of the bottom); one or two Radiolarians and a few remains of Diatoms; a few white and small green mineral particles.

Many internal casts of the Foraminifera remained after treatment with acid. These were green and grey coloured. The smaller chambers were frequently green, while the larger ones were white or grey coloured.

24th June, 1874. 400 fathoms. A blue mud containing:—Very many small sandy particles, as quartz, mica, &c.; amorphous clayey matter; many pelagic Foraminifera and a few Coccoliths; no Radiolarians and no casts of the Foraminifera noticed.

24th June, 1874. 150 and 140 fathoms. The dredge contained a blue mud, containing:—Amorphous clayey matter; many small rounded green and black particles (glauconite), as on the Agulhas Bank; many pelagic Foraminifera, a few pale internal green casts of which remained after treatment with acid.

24th and 25th June, 1874. Off D'Urville Island, New Zealand, in 75, 49, 39, 40, and 32 fathoms. All gave a blue mud containing:—Many sandy particles; amorphous matter; portions of Echinoderms; shells; shore forms of Foraminifera &c.

Wellington, New Zealand, to Fiji Islands.

Sounding 204. 8th July, 1874. 1100 fathoms. Lat. 40° 28′ S., long. 177° 43′ E. A blue mud, with a thin red top layer, containing:—Amorphous matter; many fine and coarse sandy particles, as quartz, pumice, mica, &c.; a few pelagic Foraminifera and Coccoliths; a few siliceous spines.

Sounding 205. 10th July, 1874. 700 fathoms. Lat. 37° 34′ S., long. 179° 22′ E. A blue mud, with a thin red upper layer, containing:—Amorphous clayey matter; many fine and coarse sandy particles, as quartz, pumice, &c.; a few pelagic Foraminifera and Coccoliths.

Soundings 206 and 206 A. 14th July, 1874. 520–600 fathoms. Off Kermadec Island. Traces of a grey mud came up on the sounding-tube. This contained a few pelagic Foraminifera and many sandy particles; the dredge brought up some very large pieces of pumice and some other pieces of volcanic rock.

Sounding 207. 15th July, 1874. 600 fathoms. Lat. 28° 33′ S., long. 177° 50′ W. No bottom in the sounding-tube.

The dredge brought up many pieces of pumicestone.

Sounding 208. 17th July, 1874. 2900 fathoms. Lat. 25° 5′ S., long. 172° 56′ E. A red clay containing:—Much amorphous clayey matter; many fine white mineral particles and a few larger pieces of pumice; one or two portions of Radiolaria; a few manganese grains.

No trace of carbonate of lime in this sounding. The fine mineral particles appeared to be broken-down pieces of pumice.

Sounding 208 A. 22nd July, 1874. 18 fathoms. Inside the reef, Tongatabu. A coral-mud containing:—Some amorphous calcareous matter; débris of coral reefs; immense numbers of Orbitolites, and a few other shore forms of Foraminifera, Pteropods, &c.

22nd July, 1874. 240 fathoms. Outside the reef, Tongatabu. A coral-mud containing:—Much amorphous calcareous matter; débris of coral reefs; pelagic and other Foraminifera, &c.

24th July, 1874. 315 fathoms. Off Matuka Island, Fiji Islands. A coral-mud containing:—Much amorphous calcareous matter; débris of coral; pelagic Foraminifera, Pteropods, Heteropods, and other surface shells and shore forms of Foraminifera; a few black mineral particles.

Off Kandavu, Fiji Islands. 3rd August, 1874. 140 fathoms. Inside the reef. A coral-mud containing:—Much amorphous calcareous matter; shore forms of Foraminifera, Pteropods, spicules of sponges, &c.; a few green and red mineral particles.

3rd August, 1874. 255 and 210 fathoms. Outside the reef, Kandavu. A coral-mud containing:—Much amorphous calcareous matter; débris of coral; Pteropods, Heteropods, and surface Gasteropods; pelagic and other Foraminifera, Coccoliths, and Rhabdoliths; a few sponge-spicules; a few green and red mineral particles.

A few internal casts of the Foraminifera and Pteropods remained after treatment with acid.

Sounding 209. 3rd August, 1874. 610 fathoms. A coral-mud containing:—Amorphous calcareous and some red clayey matter; many Pteropod, Heteropod, larval Gasteropod, and Lamellibranch shells; pelagic Foraminifera, Coccoliths, and Rhabdoliths; a few red and white mineral particles and rather large pieces of pumice.

Sounding 210. 12th August, 1874. 1350 fathoms. Lat. 19° 2′ S., long. 177° 10′ E. A *Globigerina*-ooze of a red colour containing:—Some amorphous calcareous and clayey matter; very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; very small mineral particles, as pumice; a black scoria-like mineral and manganese grains; one or two broken pieces of siliceous spines.

The trawl brought up many pieces of pumice, some having a slight coating of peroxide of manganese.

Sounding 211. 15th August, 1874. 1450 fathoms. Lat. 18° 30′ S., long. 173° 52′ E. A *Globigerina*-ooze of a red colour containing:—Some amorphous calcareous and clayey matter; very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a good many small pieces of pumice and black and red mineral particles, and some manganese grains.

Many very complete casts of the Foraminifera, of a red colour, remained after treatment with acid. In many cases the red substance had coated as well as filled the shell, so that we had both an external and internal cast, the two linings connected by pillars representing the foramina of the shell.

18th August, 1874. Off Api, New Hebrides. 67, 70, and 125 fathoms. The bottom in each case was a black volcanic sand, with which were mixed Foraminifera and Pteropod shells.

Sounding 212. 19th August, 1874. 2650 fathoms. Lat. 16° 47′ S., long. 165° 20′ E. A red clay containing :—Much amorphous clayey matter; many fine mineral particles, pumice, and black and brown particles; a few manganese grains; one or two Radiolaria; no carbonate of lime.

Sounding 213. 21st August, 1874. 2325 fathoms. Lat. 15° 58′ S., long. 160° 48′ E. A red clay containing :—Much amorphous clayey matter; many small mineral particles, as pumice, mica, red mineral, &c.; a few remains of pelagic Foraminifera and a few Coccoliths.

Sounding 214. 24th August, 1874. 2450 fathoms. Lat. 14° 7′ S., long. 153° 43′ E. A red clay containing:—Much amorphous clayey matter; many very fine mineral particles, as pumice &c.; a few broken remains of pelagic Foraminifera; a few manganese grains.

Sounding 215. 25th August, 1874. 2440 fathoms. Lat. 13° 50′ S., long. 151° 49′ E. A red clay containing, in the upper half of the tube:—Much amorphous clayey matter; many fine mineral particles, as pumice &c.; a few Radiolaria; no carbonate-of-lime organisms. In the lower half of the tube a much lighter-coloured clay containing:—Amorphous clayey matter; fine mineral particles; a few Radiolaria; a great many pelagic Foraminifera and Coccoliths, which appeared to be entirely absent in the upper layers.

The trawl brought up many pieces of pumice, varying from the size of a pea to that of an egg.

Sounding 216. 27th August, 1874. 2275 fathoms. Lat. 13° 6′ S., long. 148° 37′ E. A small quantity of bottom came up, which indicated a grey clay containing :—Amorphous clayey matter; fine mineral particles; a few pelagic Foraminifera, Coccoliths, and Rhabdoliths.

Sounding 217. 28th August, 1874. 1700 fathoms. Lat. 13° 42′ S., long. 146° 46′ E. A *Globigerina*-ooze of a light brown colour containing :—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; amorphous clayey matter; some fine mineral particles; one or two parts of Radiolaria.

Sounding 218. 29th August, 1874. 1400 fathoms. Lat. 12° 8′ S., long. 145° 10′ E. A *Globigerina*-ooze of a light brown colour containing :—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths;

a good deal of amorphous clayey and calcareous matter; fine mineral particles (pumice); a few siliceous spines.

The trawl contained several pieces of water-logged cocoanut wood and some pieces of pumice.

Soundings inside the Barrier reef gave:—A coral-mud, made up of much amorphous calcareous matter, débris of coral, Foraminifera, &c.

9th to 16th September, 1874. 10 to 70 fathoms. The soundings and dredgings between Cape York and the Arru Islands, across the Arafura Sea, were all shallow water, 10 to 70 fathoms. In each case the bottom was a green mud containing:—Many sandy particles, as quartz, mica, and rounded mineral particles of a green and black colour; much amorphous green-coloured clayey matter; broken pieces of shell; shore forms of Foraminifera, as Textularias, Rotalias, &c., and *Echini*-spines &c.; a few remains of Diatoms.

After treatment with acid there always remained internal casts of the Foraminifera. Pelagic Foraminifera, Coccoliths, Rhabdoliths, Pteropods, and Radiolaria appeared to be nearly or quite absent in the bottom and in the surface-waters.

Cape York to Hongkong.

Sounding 219. 23rd September, 1874. 800 fathoms. Lat. 5° 41′ S., long. 134° 4′ E. A green mud containing:—Much green amorphous clayey matter; many small mineral particles of a white, black, and green colour; a few pelagic and other Foraminifera; a few Radiolarians and Diatoms.

Sounding 220. 24th September, 1874. 580 fathoms. Lat. 5° 26′ S., long. 133° 19′ E. A green mud containing:—Green-coloured amorphous matter; very many pelagic Foraminifera, Pteropods, and Coccoliths; a great many small mineral particles; one or two Radiolaria and a few Diatoms.

Many pale-green casts of the Foraminifera remained after treatment with acid. A section of 2 feet 3 inches came up in the tube; the lower layers were of a blue rather than a green colour, and contained fewer Foraminifera than the upper layers.

26th September, 1874. 129 fathoms. A blue mud containing:—A great many pelagic Foraminifera and some Pteropod shells.

These were imbedded in a fine amorphous mud of a blue colour. In the dredge there came up some large pieces of rock, which required a sharp blow with a hammer to break. They contained many Foraminifera, and appeared to be merely hardened portions of the bottom.

Sounding 221. 28th September, 1874. 2800 fathoms. Banda Sea. Lat. 5° 24′ S., long. 130° 37′ E. A blue mud with a red upper layer, containing:—Amorphous clayey matter; many fine and a few rather coarse mineral particles of a white, green, and black colour; a few Radiolarian remains; no carbonate of lime.

29th September, 1874. 200 fathoms. Bottom composed of pebbles and sandy particles, and a few pelagic Foraminifera.

Sounding 222. 3rd October, 1874. 1425 fathoms. Lat. 4° 21′ S., long. 129° 7′ E. A blue mud with reddish upper layer, containing:—Much amorphous clayey matter; many sandy particles of a green and black colour and pumice; many pelagic Foraminifera and Coccoliths; a good many Radiolaria.

The trawl brought up soft mud of a brownish colour, in which were imbedded some large lumps of blue mud, also pieces of wood and fruits.

Molucca Passage. 13th October, 1874. 825 fathoms. Lat. 0° 48′ S., long. 126° 58′ E. Sounding 223. No bottom came up.

Sounding 224. 14th October, 1874. 1200 fathoms. Lat. 0° 41′ N., long. 126° 37½′ E. A small quantity of bottom came up, which indicated a grey mud, containing:—Very many particles of volcanic sand; a few Foraminifera and Radiolaria.

Celebes Sea.

Sounding 225. 20th October, 1874. 2150 fathoms. Lat. 2° 55′ N., long. 124° 53′ E. A grey or red mud, containing:—Amorphous clayey matter; many fine mineral particles of black, green, and red colour (pumice); a good many Radiolaria; no carbonate of lime.

Sounding 226. 22nd October, 1874. 2600 fathoms. Lat. 5° 44′ N., long. 123° 34′ E. A grey or brown mud, containing:—Red amorphous clayey matter; very many fine and coarse mineral particles, as quartz, mica, and green minerals; a few Radiolaria; no carbonate of lime.

23rd October, 1874. 255 fathoms. A small quantity of bottom came up, which indicated a green mud, containing:—Amorphous clayey matter; many mineral particles; pelagic Foraminifera; Coccoliths; *Acanthometra*-spines and Diatoms.

Sulu Sea.

26th October, 1874. 98 and 102 fathoms. Several basaltic pebbles came up in the sounding-tube. In the dredge there was a large pebble covered with *Carpenteria* (c. f.).

Sounding 227. 27th October, 1874. 2550 fathoms. Lat. 8° 32′ N., long. 121° 55′ E. A blue mud with reddish upper layer, containing:—Very many fine particles of minerals—quartz, mica, and a green and a red mineral; a few Radiolaria and Diatoms; one or two *Globigerina* and Coccoliths; a few manganese grains.

2nd November, 1874. 100 fathoms. A green mud containing:—Amorphous matter; many pelagic and other Foraminifera; Pteropods, Heteropods, surface Gasteropods, and larval Lamellibranch shells; many quartz, mica, and green and black mineral particles; a few siliceous spines.

Very complete casts of the carbonate-of-lime organisms in pale green remained after treatment with acid.

2nd November, 1874. 705 fathoms. Lat. 12° 24′ N., long. 122° 15′ E. A green mud containing:—Much amorphous clayey matter; very many fine mineral particles of quartz, mica, and a green mineral; a few pelagic Foraminifera and a few broken pieces of Pteropods and other surface shells; a few Coccoliths.

China Sea.

Sounding 229. 13th November, 1874. 1050 fathoms. Lat. 16° 42′ N., long. 119° 22′ E. A grey mud containing:—A great deal of amorphous clayey matter; many fine black, white, and green mineral particles; a good many pelagic Foraminifera; a few Coccoliths; one or two manganese grains.

China and Sulu Seas.

Sounding 230. 8th January, 1875. 2100 fathoms. Lat. 17° 54′ N., long. 117° 14′ E. A blue mud with reddish upper layer, containing:—Much amorphous clayey matter; many fine white and a few large black mineral particles; a good many Radiolarian remains; one or two broken pieces of Radiolarians.

Sounding 231. 16th January, 1875. 700 fathoms. Lat. 12° 21′ N., long. 122° 15′ E. A blue mud containing:—Amorphous clayey matter; many fine mineral particles; a few Globigerinas, Pulvinulinas, and Orbulinas; Pteropods and Coccoliths; a few Radiolarian remains and Diatoms.

22nd January, 1875. 90 to 150 fathoms. *Euplectella*-ground, Zebu. A soft blue mud containing:—Amorphous clayey matter; many fine sandy particles; a few pelagic and other Foraminifera; a few shells of larval Gasteropods and Lamellibranchs; a few siliceous spines.

25th January, 1875. 375 fathoms. Sounding 232. Lat. 9° 26′ N., long. 123° 45′ E. A blue mud containing:—Amorphous clayey matter; very many fine mineral particles; a few pelagic and other Foraminifera; Pteropod and other surface shells; a few Radiolarian and Diatom remains.

26th January, 1875. 185 fathoms. Off Camiguin Island, New Volcano. A green mud containing:—Very many red, white, and black mineral particles; green amorphous clayey matter; a few pelagic Foraminifera; Pteropod and other shells; a few *Acanthometræ* and Diatom remains.

Sounding 233. 28th January, 1875. 2225 fathoms. Lat. 8° 0′ N., long. 121° 42′ E. A blue mud with an upper red layer, containing:—Much amorphous clayey matter; many fine mineral particles of a white, black, and green colour. A good many Diatoms and Radiolaria; one or two small pieces of pelagic Foraminifera.

Sounding 234. 8th February, 1875. 2050 fathoms. Lat. 5° 47′ N., long. 124° 1′ E. A blue mud with an upper reddish tinge, containing:—Amorphous clayey matter; many fine and coarse minerals; a great many Diatom and Radiolarian remains; one or two broken portions of pelagic Foraminifera; a few manganese grains.

Dredge brought up some hardened lumps of the bottom; these were traversed by black streaks (manganese), and had imbedded in them some pieces of wood.

Sounding 235. 10th February, 1875. 500 fathoms. Lat. 4° 33′ N., long. 127° 6′ E. A grey ooze containing:—Very many pelagic Foraminifera, Pteropods, and other surface shells; many coarse and fine mineral particles of a white, black, and green colour; a few pale white casts of the Foraminifera.

The dredge brought up some large, flat, hardened pieces of the bottom.

Sounding 236. 12th February, 1875. 2550 fathoms. Lat. 4° 19′ N., long. 130° 15′ E. A red clay containing:—Much amorphous clayey matter; many very fine white mineral particles; a good many Radiolaria and Diatoms; a few manganese grains.

The trawl brought up several pieces of pumice about the size of a hen's egg.

Sounding 237. 16th February, 1875. 1675 fathoms. Lat. 2° 46′ N., long. 133° 58′ E. A *Globigerina*-ooze containing:—Very many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a great many Radiolaria and a few Diatom-remains; amorphous clayey and calcareous matter and a few fine mineral particles.

Sounding 238. 16th February, 1875. 2000 fathoms. Lat. 2° 56′ N., long. 134° 11′ E. A *Globigerina*-ooze of a red colour, containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; much clayey matter; many fine mineral particles (pumice); a good many Radiolaria.

The trawl contained many small pieces of pumice from the size of a marble to that of a hen's egg. Some of these had a slight coating of manganese.

Sounding 239. 22nd February, 1875. 2000 fathoms. Lat. 0° 39′ S., long. 138° 55′ E. A blue mud containing:—Much amorphous clayey matter; many fine mineral particles (pumice &c.); a good many Radiolaria; a few broken pieces of pelagic Foraminifera.

Humboldt Bay, New Guinea. 24th February, 1875. 37 fathoms. A green mud containing:—Many mineral particles and amorphous matter; many shore forms of Foraminifera; a few Globigerinas, Pteropods, and other surface shells; a few green internal casts of Foraminifera.

Sounding 240. 1st March, 1875. 1075 fathoms. Lat. 2° 33′ S., long. 144° 4′ E. A blue mud with a red upper layer, containing:—Much amorphous clayey matter; fine black, white, and green mineral particles (pumice); a great many pelagic Foraminifera and Coccoliths; a great many Radiolaria.

In the trawl there were several large pieces of pumicestone, pieces of wood and fruits, and a few large Pteropod and *Ianthina*-shells.

Nares Harbour, Admiralty Islands. 7th March, 1875. 25 to 16 fathoms. Dredgings inside the harbour gave coral-muds and black sandy muds, or a mixture of these. In some places live coral.

Admiralty Islands to Japan.

10th March, 1875. Outside Nares Harbour, 152 fathoms. Some traces came up on the tube which indicated a green mud, containing:—Many mineral particles; débris of coral, Foraminifera, &c.

Sounding 241. 11th March, 1875. 1100 fathoms. Lat. 0° 43′ S., long. 147° 0′ E. A *Globigerina*-ooze containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a good many Radiolarian remains; amorphous clayey and calcareous matter; some fine white and black mineral particles (pumice).

Several pumicestones came up in the dredge.

Sounding 242. 13th March, 1875. 2650 fathoms. Lat. 0° 40′ N., long. 148° 41′ E. A red clay containing:—Much amorphous clayey matter; many very fine mineral particles; one small piece of pumice; a good many Radiolarians; a good many manganese grains.

Sounding 243. 16th March, 1875. 2450 fathoms. Lat. 2° 15′ N., long. 146° 16′ E. A red clay containing:—Much amorphous clayey matter; very fine mineral particles; a great many Radiolaria; a few broken pieces of pelagic Foraminifera; some manganese grains.

Sounding 244. 19th March, 1875. 2325 fathoms. Lat. 5° 31′ N., long. 145° 13′ E. A grey clay containing:—Much amorphous clayey and some calcareous matter; fine mineral particles (a red and yellow cherty-like mineral); a good many pelagic Foraminifera; a great many Radiolaria.

Several small pieces of pumice came up in the trawl.

Sounding 245. 21st March, 1875. 1850 fathoms. Lat. 7° 45′ N., long. 144° 20′ E. A *Globigerina*-ooze with red tinge, containing:—Very many pelagic Foraminifera and Coccoliths; many Radiolaria;

some amorphous clayey and calcareous matter, and a few mineral particles.

In the trawl were one or two small pieces of pumice.

Sounding 246. 23rd March, 1875. 4575 fathoms. Lat. 11° 24′ N., long. 143° 16′ E. A trace came up on the outside of the tube which indicated a Radiolarian ooze the same as described below, No. 247.

Sounding 247. 23rd March, 1875. 4475 fathoms. Lat. 11° 24′ N., long. 143° 16′ E. A Radiolarian ooze (upper layers red, lower layers pale straw-colour), containing chiefly the remains of Radiolaria, Diatoms, Challengerias, and other deep-sea Rhizopods (see notes on Surface Animals, p. 535); one or two white mineral particles (pumice?); one or two pieces of a yellow and green mineral (flinty concretion?); a very small quantity of amorphous clayey matter; many small peroxide of manganese particles.

A section of about 3 inches came up in the tube; the upper 2 inches were of a red colour, and contained very many of the small manganese particles. These manganese grains apparently gave the colour to these layers. The lower inch of the section was of a pale yellow colour, and contained relatively many fewer manganese grains. In all other respects the two layers appeared the same. The lower layer was to the look and touch very much like the Diatomaceous ooze taken in the South Atlantic. It also caked in the same way.

Sounding 248. 25th March, 1875. 2300 fathoms. Lat. 14° 44′ N., long. 142° 13′ E. A red or chocolate clay containing:—Much amorphous clayey matter; many very fine mineral particles; a great many Radiolaria and Challengerias; one or two broken pieces of pelagic Foraminifera; many manganese grains.

The trawl brought up several pumicestones coated with manganese, and some hardened pieces of the bottom.

Sounding 249. 27th March, 1875. 2475 fathoms. Lat. 17° 29′ N., long. 141° 21′ E. A red or chocolate clay, containing:—Much amorphous clayey matter; many fine and some coarse mineral particles—quartz, mica, pumice, &c.; a few Radiolarians; one or two broken pieces of pelagic Foraminifera; many manganese grains.

Sounding 250. 9th March, 1875. 2450 fathoms. Lat. 19° 24′ N., long. 141° 13′ E. A red clay containing:—Much amorphous clayey matter; many fine and some rather coarse mineral particles (some of these pieces of areolar pumice of a green colour, and containing white crystals); a few Radiolarians and other siliceous remains; a few manganese grains.

Sounding 251. 1st April, 1875. 2500 fathoms. Lat. 22° 1′ N., long. 140° 27′ E. A red clay, same as No. 250.

Sounding 252. 5th April, 1875. 2425 fathoms. Lat. 26° 29′ N., long.

137° 57′ E. A red clay containing:—Much amorphous clayey matter; many small mineral particles of a white and black colour; many Radiolarian, Diatom, and *Challengeria* remains; a few manganese remains.

Sounding 253. 9th April, 1875. 2250 fathoms. Lat. 31° 8′ N., long. 137° 8′ E. A blue mud with reddish upper layer, containing:—Much amorphous blue clayey matter; many fine and a few rather coarse mineral particles; many remains of *Challengeria*, Radiolaria, and Diatoms; two pieces of pelagic Foraminifera noticed.

Japan.

Sounding 254. 12th May, 1875. 345 fathoms. *Hyalonema*-ground. A green mud containing:—Much amorphous clayey matter; many mineral particles of a green, white, and black colour; a few pelagic and other Foraminifera; Coccoliths and broken pieces of Pteropods and other shells; a good many Diatom and Radiolarian remains; a few casts of Foraminifera of a pale green colour.

Inland Sea, Japan. 19th to 31st May, 1875. 8 to 20 fathoms. Soundings and dredgings in the Inland Sea, Japan, gave always a blue mud containing:—Amorphous clayey matter; many mineral particles—mica, quartz, red and green minerals; broken pieces of large Gasteropods and Lamellibranch shells; spines of *Echini*, valves of *Cypridina*, and shore forms of Foraminifera.

Shells or tests of pelagic Foraminifera, Pteropods, and Polycystina were apparently wanting in these bottoms.

Sounding 255. 3rd June, 1875. 2675 fathoms. Lat. 32° 31′ N., long. 135° 39′ E. A blue mud with red upper layer containing:—Much amorphous blue clayey matter; many fine mineral particles—mica, pumice, &c.; very many Diatom, *Challengeria*, and Radiolarian remains; two shore forms of Foraminifera noticed; no pelagic Foraminifera.

Sounding 256. 4th June, 1875. 565 fathoms. Lat. 34° 7′ N., long. 138° 0′ E. A small quantity came up which indicated a green mud containing:—Amorphous matter; many mineral particles; a good many pelagic Foraminifera; a few Diatoms.

A good many dark and light green coloured casts of the Foraminifera remained after treatment with acid. The trawl brought up some pumice-stones.

Sounding 257. 5th June, 1875. 775 fathoms. Lat. 34° 58′ N., long. 139° 30′ E. A green mud containing:—Many sandy particles of a white, green, and black colour; pelagic and other Foraminifera; Diatoms and Radiolaria.

A great many green internal casts of the Foraminifera; in the trawl were many hardened pieces of the bottom, volcanic pebbles, &c.

Japan to Honolulu, Sandwich Islands.

Sounding 258. 17th June, 1875. 1875 fathoms. Lat. 34° 37′ N., long. 140° 32′ E. A blue mud containing:—Much amorphous blue clayey matter; many fine and some coarse mineral particles of a black, red, and green colour; many remains of Diatoms, Radiolaria, and Challengerias; one or two Formanifera and Coccoliths.

In the trawl were several large pieces of pumicestone, hardened pieces of the bottom honeycombed by worm-tubes, a few large Pteropod shells, a Cephalopod's beak, and two vertebræ of fish; the surface of the pumicestones was in most cases black with peroxide of manganese; so also was the surface of the worm-tracks in the hardened pieces of the bottom.

		fathoms.	° ′	° ′
Sounding 259.	18th June, 1875.	3900.	Lat. 35 18 N.,	long. 144 8 E.
,, 260.	19th ,, ,,	3625.	,, 35 18 N.,	,, 147 9 E.

Each a red clay containing:—Much amorphous clayey matter; many fine and some rather coarse mineral particles, black and white in colour, and pieces of pumice; very many remains of Radiolarians, Diatoms, and Challengerias.

Sounding 261. 21st June, 1875. 2900 fathoms. Lat. 35° 20′ N., long. 153° 39′ E. A red clay, the lower layers lighter in colour than the top ones, containing:—Amorphous clayey matter; many fine mineral particles and a few rather large pieces of pumicestone; very many remains of Diatoms, Radiolarians, and Challengerias; a few manganese grains.

The remains of siliceous organisms made up nearly a half of this bottom in bulk.

Sounding 262. 23rd June, 1875. 2300 fathoms. Lat. 35° 41′ N., long. 157° 42′ E. A red clay, the upper layers soft, the lower ones compact and of a lighter colour, containing:—Much amorphous clayey matter; many fine mineral particles, some of them black, but the majority apparently broken-down pieces of pumice; very many Radiolarians, Diatoms, and Challengerias; a few pelagic Foraminifera and Coccoliths.

The trawl brought up many large and some small pieces of pumice, most of them having a slight coating of peroxide of manganese.

		fathoms.	° ′	° ′
Sounding 263.	24th June, 1875.	2575.	Lat. 35 29 N.,	long. 161 52 E.
,, 264.	26th ,, ,,	2800.	,, 35 24 N.,	,, 166 35 E.
,, 265.	28th ,, ,,	2900.	,, 35 22 N.,	,, 169 53 E.
,, 266.	30th ,, ,,	2775.	,, 36 23 N.,	,, 174 31 E.

In all these a red or chocolate clay containing:—Much amorphous clayey matter; very many fine mineral particles, being apparently broken-down pieces of pumice, also some rather large pieces of pumice (the size of a pea), which had frequently a coating of manganese $\frac{1}{16}$ inch in thickness; very many Diatom, Radiolarian, and *Challengeria* remains; very many manganese grains.

The trawl brought up many manganese nodules or concretions and two shark's teeth; these nodules had in most cases a nucleus of pumice.

Sounding 267. 2nd July, 1875. 205 fathoms. Lat. 36° 10′ N., long. 178° 0′ E. A grey clay containing:—Much amorphous clayey matter; many fine white mineral particles; many Radiolarian and Diatom remains; a few pelagic Foraminifera and their broken parts and Coccoliths.

Several pumicestones came up in the trawl, the smaller ones having a coating of manganese.

Sounding 268. 3rd July, 1875. 2530 fathoms. Lat. 35° 49′ N., long. 179° 57′ W. (*a*) Red clay, the upper layer in the tube 1 inch thick, containing:—Much amorphous clayey matter; many fine mineral particles; many Radiolarian and Diatom remains; some manganese grains; no carbonate-of-lime organisms.

(*b*) A grey clay, in lower part of the tube 4 inches thick, containing:—Same as in the upper layer, but, in addition, a good many pelagic Foraminifera and Coccoliths, and fewer manganese grains.

Sounding 269. 5th July, 1875. 2900 fathoms. Lat. 37° 41′ N., long. 177° 4′ W. A red clay containing:—Much amorphous clayey matter; many fine mineral particles, pieces of pumice, and black and white crystals; many Radiolarian, Diatom, and *Challengeria* remains; two broken pieces of *Globigerina* were noticed.

The trawl brought up many manganese nodules, pieces of pumice and sharks' teeth; a few of these had a coating of peroxide of manganese ¼ inch in thickness. Many of the nodules had a nucleus of pumice surrounded by ½ an inch of the black manganese; some were black manganese throughout excepting a small spot in the centre; one had a siliceous sponge (*Farrea*) imbedded in an inch of the black manganese.

				fathoms.		
Sounding 270.	7th July, 1875.			3000.	Lat. 37° 59′ N.,	long. 171° 68′ W.
„ 271.	9th	„	„	3050.	„ 37 49 N.,	„ 166 47 W.
„ 272.	10th	„	„	2900.	„ 37 37 N.,	„ 163 26 W.
„ 273.	12th	„	„	2740.	„ 37 52 N.,	„ 160 17 W.

In each case a red clay containing:—Much amorphous clayey matter; very many fine white mineral particles (pumice); very many Radiolarian, Diatom, and *Challengeria* remains; a good many manganese grains. In 270 and 271 the remains of siliceous organisms make up over one third of the bottom in bulk.

On the 12th July the trawl brought up fully a bushel of manganese nodules; these were chiefly of a rounded or kidney-shape, like a lot of potatoes, the largest being about the size of a cricket-ball: one of the largest (2 × 3 × 3 inches) contained in the centre a large shark's tooth with serrated edges; the tooth was well preserved and was about 1½ inch in length. Other nodules had smaller teeth, but the majority had a nucleus of pumice.

Sounding 274. 14th July, 1875. 3125 fathoms. Lat. 38° 9′ N., long. 156° 25′ W. A red clay containing:—Much amorphous clayey matter; very many fine mineral particles (pumice); a great many Radiolaria and manganese grains.

The dredge brought up several nodules and pumicestones. One large nodule or concretion of manganese was 12 × 8 × 2 inches, and had a nucleus of clay and hard cherty-like mineral matter; its upper surface was smooth and had one *Nodosaria* and several small pieces of pumice cemented to it by layers of manganese. Attached to its surface and living were—reticulated Rhozopod tubes, *Serpula* and other worm-tubes, Polyzoa, &c. Its inner surface was rough and uneven, and had a worm-tube attached to one edge.

				fathoms.		° ′		° ′
Sounding	275.	17th	July, 1875.	3025.	Lat.	35 13 N.,	long.	154 43 W.
„	276.	19th	„ „	2850.	„	32 30 N.,	„	154 38 W.
„	277.	21st	„ „	2950.	„	30 22 N.,	„	154 56 W.
„	278.	23rd	„ „	2875.	„	27 33 N.,	„	154 55 W.
„	279.	24th	„ „	2775.	„	26 5 N.,	„	155 8 W.

In each case a red clay containing:—Much amorphous clayey matter; many fine white mineral particles (pumice), and occasionally some small pieces of a red mineral; a few Radiolarian remains and manganese grains.

The dredge on the 21st July contained much mud, in which were a few manganese nodules, about a dozen sharks' teeth, some with a coating of manganese, and one or two pieces of pumicestone.

Sounding 280. 26th July, 1875. 2225 fathoms. Lat. 23° 3′ N., long. 156° 6′ W. A red clay containing:—Much amorphous clayey matter; many fine and some rather coarse mineral particles (pumice and red, black, and yellow minerals); a few Radiolaria and *Challengeria* remains; a few manganese grains.

Sounding 281. 27th July, 1875. 310 fathoms. Off Oahu, Sandwich Islands. Some traces of volcanic sand and coral débris on the dredge.

Honolulu to Tahiti.

Honolulu, August 1875. 4 to 16 fathoms. Inside the reefs. A blue mud containing:—Much amorphous matter; many fine mineral particles, the débris of volcanic rocks; a few Foraminifera and débris of coral.

Outside the reefs. 20 to 40 fathoms. A coral-sand containing:—Débris of coral, Polyzoa and Foraminifera, surface shells, &c.; a few black sandy particles.

Sounding 282. 12th August, 1875. 2050 fathoms. Lat. 20° 18′ N., long. 157° 13′ W. A trace of bottom came up on the tube, which indicated a grey clay containing:—Amorphous clayey matter; many remains of Radiolaria and Diatoms; one or two pelagic Foraminifera and their broken parts.

Sounding 283. 20th August, 1875. 2875 fathoms. Lat. 19° 10′ N., long. 154° 12′ W. A grey mud or sand containing chiefly:—Volcanic sand and pumice; these mineral particles were of a green colour, like the areolar lava and Pele's hair at Kilauea Hawaii, also some olivine and black particles; a great many Radiolaria, *Challengeria*, and Diatom remains; very little amorphous clayey matter.

Sounding 284. 21st August, 1875. 2650 fathoms. Lat. 17° 33′ N., long. 153° 36′ W. A grey mud containing chiefly:—The débris of volcanic rock in a finer state of division than yesterday; a great many Radiolarian and Diatom remains; rather more amorphous clayey matter than yesterday.

Sounding 285. 23rd August, 1875. 3000 fathoms. Lat. 14° 19′ N., long. 152° 37′ W. A red clay containing:—Much amorphous matter; very many fine mineral particles, red and yellow or green colour; a few Radiolarian and Diatom remains; a good many manganese particles.

Several manganese nodules came up in the trawl; these were more angular than usual and appear to have been formed on hardened portions of the bottom; some had a cherty-like nucleus with concentric coloured layers as in agate. There were some hardened pieces of bottom also in the trawl, some with just a slight coating of manganese, others perforated in various directions by worm-tracks.

Sounding 286. 25th August, 1875. 2900 fathoms. Lat. 12° 42′ N., long. 152° 1′ W. A red clay containing:—Much amorphous clayey matter; many very fine white mineral particles; a great many remains of Radiolaria, Diatoms, and *Challengeria*; a few manganese grains.

The dredge brought up much mud. In the washings were several pieces of pumice about the size of peas. One manganese nodule the size of a marble; three or four large Pulvinulinas. Over a third of the bottom made up of siliceous remains.

Sounding 287. 26th August, 1875. 2750 fathoms. Lat. 11° 11′ N., long. 152° 2′ W. A Radiolarian ooze of a brown colour containing:—Immense numbers of Radiolarians, Diatoms, and some *Challengeria* remains; some amorphous clayey matter; a few small white and some red-coloured mineral particles; a few manganese particles.

There were some yellow-coloured spots in the bottom, but it was mostly of a brown colour. It was more compact than yesterday's and contained more Radiolarians and fewer pieces of the delicate large cylindrical Diatom (see notes on Diatoms, p. 533).

Sounding 288. 28th August, 1875. 2700 fathoms. Lat. 9° 28′ N., long. 150° 49′ W. A small quantity came up, which indicated a Radiolarian ooze of a yellow colour containing:—Great numbers of Radiolarian and remains of other siliceous organisms; a few rounded, olive-coloured, and some small white mineral particles; some manganese grains.

The colour of this sounding was the same as the lower layer of our deepest sounding, 4475 fathoms, and as the yellow patches in the last sounding.

Sounding 289. 30th August, 1875. 2900 fathoms. Lat. 7° 35′ N., long. 149° 49′ E. A Radiolarian ooze of a brown colour, with a thin upper layer of a pale straw-colour, containing:—Immense numbers of Radiolarians, Diatom, *Challengeria*, and remains of other siliceous organisms; a few small white and yellow mineral particles; some amorphous clayey matter; a good many manganese grains.

There appeared to be a thin surface-layer of a yellow colour. It differed from the mass of the bottom beneath only in the relatively less abundance of manganese grains.

Sounding 290. 2nd September, 1875. 2550 fathoms. Lat. 5° 54′ N., long. 147° 2′ W. A Radiolarian ooze, upper layer yellow, lower layer brown-coloured, containing:—Immense numbers of Radiolarian, Diatom, and *Challengeria* remains; a few pelagic Foraminifera and their broken parts (Pulvinulinas, Orbulinas, Globigerinas) and some Coccoliths; some amorphous clayey matter.

The Foraminifera appeared to be confined to the top layer chiefly. There were fewer manganese grains in this sounding than in the last, and in this sounding they were more abundant in the lower than upper layer.

Sounding 291. 4th September, 1875. 2925 fathoms. Lat. 2° 34′ N., long. 149° 9′ W. A *Globigerina*-ooze, upper layers brown, lower layers cream-white colour, containing:—Very many pelagic Foraminifera and their broken-down parts, and Coccoliths; many Radiolaria; remains of other siliceous organisms; a good deal of amorphous calcareous and some clayey matter; very few mineral particles of any kind other than manganese grains.

The carbonate-of-lime organisms were most abundant in the lower layers. The upper brown layer had carbonate-of-lime and siliceous organisms in nearly equal proportions, and this layer had more clayey matter and manganese grains than the one underneath.

Sounding 292. 6th September, 1875. 2425 fathoms. Lat. 0° 33′ S., long. 151° 34′ W. A white *Globigerina*-ooze containing:—Great numbers of pelagic Foraminifera, their broken-down parts, and Coccoliths; a good many Radiolarians and some broken Diatoms; some amorphous calcareous but very little clayey matter.

Few, if any, mineral particles other than manganese grains, of which there were a few. A good deal of the bottom came up in the tow-net attached to the trawl. In the washings there was one piece of pumice about the size of a hen's egg.

Sounding 293. 8th September, 1875. 2600 fathoms. Lat. 3° 48′ S., long. 152° 56′ W. A Radiolarian ooze of brown colour containing:—Immense numbers of Radiolaria, Diatoms, and *Challengeria*; a few broken pieces of large pelagic Foraminifera, and one or two perfect specimens; a little amorphous clayey matter.

Few, if any, mineral particles other than the manganese particles, which were abundant. One of these last (about the size of a pea), which I broke, appeared to be formed on a nucleus of pumice.

In the trawl were several manganese nodules; one, the size of a hen's egg, appeared to be formed on a nucleus of ordinary pumice. Also one areolar piece of pumice (or lava) of a green colour like that from the Sandwich Islands. Several yellow and red cherty-like pieces of mineral.

Sounding 294. 9th September, 1875. 2350 fathoms. Lat. 5° 0′ S., long. 152° 26′ W. A Radiolarian ooze of a chocolate-colour containing:—Great numbers of Radiolaria and the broken exuviæ of these and other siliceous organisms; a few pelagic Foraminifera and their broken parts; a few Coccoliths; a few red and yellow mineral particles; manganese grains in great abundance.

Sounding 295. 11th September, 1875. 2750 fathoms. Lat. 7° 25′ S., long. 152° 15′ W. A Radiolarian ooze of a chocolate-colour containing:—Great numbers of Radiolaria and the exuviæ of other siliceous organisms; many pieces of black manganese, some pieces of red and yellow minerals, these latter being perfect crystals, and some pieces of pumicestones; some amorphous clayey matter; a few broken pieces of pelagic Foraminifera.

The trawl brought up fully a peck of manganese nodules and some mud. Amongst the nodules were some with a nucleus of pumice, of sharks' teeth, and of the ear-bones of cetaceans; some of the sharks' teeth had a very light coating of manganese.

Sounding 296. 14th September, 1875. 2610 fathoms. Lat. 11° 11′ S., long. 150° 30′ W. A dark chocolate clay containing chiefly:—Small yellow crystals and rounded particles of a red mineral about the size of a pea; very many manganese particles and grains; a few pieces of Radiolarian tests; a few small sharks' teeth; amorphous clayey matter.

Sounding 297. 16th September, 1875. 2350 fathoms. Lat. 13° 28′ S., long. 149° 30′ W. In the top of the tube a *Globigerina*-ooze of a light brown colour containing:—Very many pelagic Foraminifera and Coccoliths; amorphous clayey matter and many small yellow crystals and particles of the peroxide of manganese. In the lower part of the tube a dark chocolate clay containing:—Very many small yellow crystals; pieces of a red and yellow mineral and pumice particles; many small sharks' teeth; amorphous clayey matter, and great numbers of manganese particles and grains.

The transitions from the dark chocolate clay at the bottom to the light brown *Globigerina*-ooze on the top was very gradual, the lighter colour and the carbonate of lime increasing *pari passu*. The yellow crystals and manganese particles were most abundant in the lower portions of the tube. Radiolaria and other siliceous remains were almost wanting in this bottom.

The trawl brought up about half a ton of manganese nodules, some small pieces of pumice, several sharks' teeth, one of which was 3 inches across the base. Some of these were deeply and others only slightly coated with manganese.

Sounding 298. 17th September, 1875. 2325 fathoms. Lat. 15° 7′ S., long. 149° 41′ W. This bottom nearly the same as described for yesterday. It had, however, more mineral particles and fewer of the small yellow crystals in all its parts; also few manganese particles.

Sounding 299. 18th September, 1875. 1525 fathoms. Lat. 17° 13′ S., long. 149° 33′ W. A grey mud containing:—Amorphous clayey matter; many fine and coarse mineral particles of a white, red, and yellow colour; many pelagic Foraminifera; Coccoliths and Rhabdoliths; one or two portions of Radiolaria.

Off Tahiti, Society Islands.

Sounding 300. 20th October, 1875. 420, 590, 620, and 680 fathoms. In each case a grey or blue mud containing:—Very many particles of volcanic sand and amorphous matter; débris of coral; pelagic and other Foraminifera; larval Gasteropods and Lamellibranchs; *Echini*-spines &c. In the two deeper ones there was a red surface-layer.

Just outside the reefs at Tahiti there was a coral-mud containing a few mineral particles; inside the reefs there was a soft blue mud.

Tahiti to Valparaiso.

Sounding 301. 4th October, 1875. 1940 fathoms. Lat. 18° 40′ S., long. 149° 52′ W. A grey *Globigerina*-ooze containing:—Very many pelagic Foraminifera; Coccoliths and Rhabdoliths; some amorphous clayey and calcareous matter; some manganese grains; a good many rather coarse mineral particles of a brown and black colour; a good many internal and external casts of the Foraminifera in a red substance, as on 15th August, 1874.

Two or three hardened pieces of the bottom, coated with manganese, were in the trawl.

Sounding 302. 6th October, 1875. 2385 fathoms. Lat. 22° 21′ S., long. 150° 17′ W. No bottom came up in the sounding-tube. The trawl brought up some dark chocolate clay and many manganese nodules and sharks' teeth. Washing away the amorphous matter from some of the bottom there remained a large amount of sediment, consisting almost entirely of small rounded red mineral particles. Many of these had the form of both Foraminifera and Radiolaria; and it seemed as if some substance had been deposited in and on these organisms. There were also many manganese particles; one or two pelagic Foraminifera.

In the washing of the mud in the trawl were great numbers of sharks' teeth, the largest being 4 inches across the base. One piece of manganese concretion measured 18 × 12 × 2 inches, and had a mass of soft red or yellow clay in the centre. There were two or three pieces of pumice.

Sounding 303. 7th October, 1875. 2450 fathoms. Lat. 23° 35′ S., long. 150° 3′ W. A dark brown clay, same as described yesterday, containing:—Amorphous clayey matter; rounded yellow minerals, many Radiolarian-shaped; pieces of pumice and other minerals; very many manganese particles; a few Radiolaria.

Sounding 304. 9th October, 1875. 2075 fathoms. Lat. 26° 9′ S., long. 145° 17′ W. In the upper part of the tube a *Globigerina*-ooze of a light brown colour containing:—Very many pelagic and other Foraminifera; Coccoliths, Rhabdoliths, and *Echini*-spines; small yellow crystals and pieces of a red and yellow cherty-like mineral; some amorphous clayey matter. In the lower part of the tube a dark chocolate clay containing:—Much amorphous clayey matter; very many yellow crystals and pellets of peroxide of manganese; a few broken pelagic Foraminifera.

The transition from the one to the other deposit was quite gradual. This sounding was very like that on 16th September last.

Remains of Radiolaria and other siliceous organisms appeared to be entirely wanting in this sounding.

Sounding 305. 11th October, 1875. 1985 fathoms. Lat. 28° 22′ S., long. 141° 22′ W. A *Globigerina*-ooze of light yellow colour containing:—Great numbers of pelagic Foraminifera; Coccoliths and Rhabdoliths; *Echini*-spines; a good many Radiolarian remains; amorphous clayey matter and manganese grains; a few pieces of vesicular lava, of a green colour, like that at the Hawaiian Islands.

Sounding 306. 14th October, 1875. 2375 fathoms. Lat. 32° 36′ S., long. 137° 43′ W. A dark chocolate clay containing:—Amorphous clayey matter; many small yellow crystals and pumice; pieces of red cherty-like mineral; many manganese grains and pellets; a few remains of pelagic Foraminifera.

The trawl brought up some mud and over a bushel of manganese nodules and some pieces of pumice. Amongst the nodules were:—Many sharks' teeth, some deeply imbedded in manganese; eight tympanic bones of Cetaceans, some deeply imbedded in manganese. Some nodules had a nucleus of bone, some of pumice, some a cherty-like mineral with agate bands.

Sounding 307. 16th October, 1875. 2335 fathoms. Lat. 33° 29′ S., long. 133° 22′ W. In upper part of tube, 2 inches, a dark chocolate clay containing:—Much amorphous clayey matter; many small yellow crystals, pieces of a cherty-like mineral, and many manganese grains and pellets; a few remains of pelagic Foraminifera. In lower part of the tube, 5 inches, a light brown clay containing, besides the things in the upper layer:—Many more pelagic Foraminifera, and immense numbers of Coccoliths.

The lighter colour of the lower layers appeared to be due to the greater abundance of carbonate-of-lime organisms, and consequently less abundance of manganese particles.

This arrangement of the contents of the sounding-tube is the reverse of that on the 9th inst.

The trawl brought up over a bushel of nodules &c., as:—

Over 100 sharks' teeth,
About 30 tympanic bones of Cetaceans,
Portions of other bones,
One granitic pebble,
Grey concretions of the bottom.

} All these had a more or less coating of peroxide of manganese.

Also some nodules with no apparent nucleus, and some with a hard cherty yellow mineral in the centre.

Sounding 308. 19th October, 1875. 2400 fathoms. Lat. 36° 33′ S., long. 132° 55′ W. A dark chocolate clay containing:—Amorphous clayey matter; many manganese grains; small yellow crystals, rounded pellets of a red-brown mineral; a few pieces of pelagic Foraminifera.

The remains of the Foraminifera appeared to be confined to the upper layer.

Sounding 309. 21st October, 1875. 2600 fathoms. Lat. 40° 8′ S., long. 132° 56′ W. A chocolate clay containing:—Amorphous clayey matter; many manganese grains and pellets; small crystals, same as in late soundings, but had not the yellow colour; angular pieces of a cherty-like mineral; small teeth of sharks.

There was a section of over a foot; it was of a chocolate-colour throughout, except two small yellow spots.

Sounding 310. 23rd October, 1875. 2550 fathoms. Lat. 39° 47′ S., long. 131° 20′ W. Two small pieces of manganese and three small pieces of a cherty-like mineral in the tube; a trace of brown mud on the outside of the tube indicating a bottom like the last.

In the trawl were many rounded manganese nodules to which some traces of mud adhered. The nodules had nuclei of sharks' teeth, tympanic bones of cetacea, agate-like minerals, pieces of bones; and in all cases these were deeply imbedded in manganese, in some cases a coating of over an inch in concentric layers. It is curious and significant that not much (other than a trace) clay came up in the sounding-tube, the bag of the trawl, or in the tow-nets attached to the trawl and weight. All this indicates that the manganese was in great abundance at this spot.

Sounding 311. 25th October, 1875. 2300 fathoms. Lat. 39° 16′ S., long. 124° 7′ W. A streak of black manganese on the outside of the tube, as if it had been rubbed against a nodule. A small portion of mud adhered to the water-bottle, which indicated a dark chocolate clay containing:—Amorphous clayey matter; much manganese; piece of a red mineral; a few remains of pelagic Foraminifera and some Coccoliths.

Sounding 312. 27th October, 1875. 2250 fathoms. Lat. 39° 13′ S., long. 118° 49′ W. On the outside of the tube a streak of manganese, as if it had struck a nodule. Inside the tube a little light brown clay containing:—Amorphous clayey matter; many particles of a black manganese and of a red mineral; a good many pelagic Foraminifera and Coccoliths.

The trawl brought up one small manganese nodule. The frame of the trawl had many streaks of manganese.

Sounding 313. 29th October, 1875. 1600 fathoms. Lat. 38° 44′ S., long. 112° 34′ W. A *Globigerina*-ooze containing:—Great numbers of pelagic and a few other Foraminifera; many Coccoliths and Rhabdoliths; many manganese grains and one or two particles of a red mineral.

There was very little amorphous matter in this sounding; the brown colour is due to the presence of the manganese grains.

Sounding 314. 1st November, 1875. 2025 fathoms. Lat. 39° 4′ S., long. 105° 5′ W. A *Globigerina*-ooze of a red colour containing:—Very many pelagic Foraminifera and others; Coccoliths and Rhabdoliths and *Cypridina*-valves; some amorphous clayey matter; many manganese particles, and some particles of red, yellow, and black minerals.

The lower layers were of a darker colour than the upper ones, and contained less carbonate of lime. About a dozen manganese nodules and two shark's teeth came up in the trawl. Two nodules had a nucleus of obsidian (?), outside this several agate-like bands, and then many layers of the peroxide of manganese. Two other nodules, from the structure and presence of lime, appeared to be formed on a nucleus of bone. One of the shark's teeth was deeply imbedded, the other was not.

Sounding 315. 3rd November, 1875. 2270 fathoms. Lat. 39° 22′ S., long. 98° 46′ W. A dark chocolate clay containing:—Much amorphous clayey matter; many manganese particles, small yellow crystals, red, white, and black mineral particles (quartz and particles of volcanic sand?). In the upper layers there were a good many remains of pelagic Foraminifera and a few Coccoliths, but these were almost wanting in the deeper layers.

Sounding 316. 5th November, 1875. 1500 fathoms. Lat. 38° 7′ S., long. 94° 4′ W. A small quantity of bottom came up which indicated a *Globigerina*-ooze of a brown colour containing:—Many pelagic Foraminifera, *Cypridina*-valves, and *Echini*-spines; many manganese particles, and a good many rather coarse sandy particles of a green colour (serpentine?); a few Radiolaria.

Most of the finer portions of the bottom appeared to have been washed out of the tube on the way up.

The tow-nets at the trawl contained many particles of a green mineral and one pebble of the same nature (serpentine?), with a coating of manganese.

Sounding 317. 9th November, 1875. 1825 fathoms. Lat. 38° 6′ S., long. 88° 2′ W. A *Globigerina*-ooze of a brown colour containing:—Many pelagic Foraminifera, Coccoliths, and Rhabdoliths; a good many manganese particles and pieces of a red and yellow mineral; one Radiolarian noticed; some amorphous clayey matter.

In the lower end of the tube the bottom was of a much darker colour, and contained fewer Foraminifera and more manganese and amorphous matter.

In the trawl there was some mud, all of a brown colour, same as in the upper part of the sounding-tube. In the sifting were many pellets of manganese and pieces of a flinty-like mineral.

Sounding 318. 11th November, 1875. 1775 fathoms. Lat. 37° 29′ S., long. 83° 7′ W. A *Globigerina*-ooze of a brown colour. No bottom came up in the tube.

I here copy *in extenso* from my Journal notes so far as they relate to the bottom in the trawl:—

"The trawl came up in the afternoon fouled, but in it were three or four quarts of manganese nodules varying from the size of a hen's egg to that of a pea.

"The weights (300 fathoms from the trawl) were all scored and marked with streaks of black, as if they had been dragged over lumps of manganese.

"The tow-net just behind these weights had in it very many *Globigerinæ*, *Pulvinulinæ*, and one or two *Orbulinæ* (all dead), a good many manganese pellets and a very little mud.

"This net would seem to have caught the particles knocked up by the weights in front. One of the tow-nets at the trawl was full to the brim of a yellow or, rather, light-brown-coloured mud, in which were many manganese nodules. Being so full of mud, not much of the finer portions of the bottom could have been washed away; hence this tow-net of mud gives us information from which some idea may be formed of the ratio which the manganese nodules bear to the ooze. In a peck of the mud there was a little over a quart of manganese nodules. The nodules were all nearly round. Some of the smaller ones were composed of the black manganese to the centre, while some had just a small yellow spot in the centre. Some of the larger ones had a yellow or dark green nucleus of about half an inch in diameter, which was surrounded by concentric layers of peroxide of manganese of half an inch in thickness. The yellow or green nucleus was soft, and could be cut with the knife like new cheese. Under the microscope it presented a mottled appearance, with yellow and light- and dark-green spaces, many of these being partially surrounded with agate bands.

"Foraminifera could also be seen imbedded in the mass; but all the carbonate of lime had been removed, strong nitric acid having no effect on any part of this nucleus. Birds'-feet-like extensions of the black manganese ramified into the yellow nucleus; and it seemed as if the manganese was extending into the nucleus as well as being deposited in concentric layers around it, as in those instances where pumice forms the nucleus of a nodule. There were lumps of the bottom in the tow-net which seemed to show the beginning of this process of nodule-formation. These lumps, which were of a redder colour than the rest of the bottom, seemed to be cemented by a red substance (?).

"Examined a portion of the bottom in the same way as usual with the soundings. It contained:—many Globigerinas, Pulvinulinas (the pyramidal variety), and a few Orbulinas; one or two Uvigerinas, and some Biloculinas and others; two arenaceous forms of Foraminifera, the tests composed of particles of manganese and a red mineral; many Coccoliths and Rhabdoliths; only two portions of siliceous spines and three Radiolaria were observed.

"Removing the manganese from the washing there remained:—A good many mineral particles (these were almost all of a dark lead-colour and very areolar structure, reminding one of volcanic ash and scoria); one small yellow crystal, several pieces of a red cherty-like mineral, and one quartz-like particle were noticed; manganese grains were abundant."

Sounding 319. 17th November, 1875. 2225 fathoms. Lat. 34° 7′ S., long. 73° 56′ W. A blue mud with a red upper layer containing:—Much amorphous blue clayey matter; many very fine mineral particles of quartz, mica, and a few of the green glauconitic particles; a good many Radiolaria and Diatoms.

The top layers contained no carbonate-of-lime organisms. In those in the lower part of the tube there were a pelagic Foraminifer and Coccoliths. The tow-nets at the trawl each contained a little red mud without any pelagic Foraminifera. On the framework of the trawl were several large patches of blue mud.

REMARKS ON THE FOREGOING LIST.

Several kinds of deposits have been indicated in the foregoing list. For the present these may be classed under the following heads:—

1. *Shore-deposits.*
   (*a*) Blue and green muds.—Met with near the shores of most of the great continents and islands.
   (*b*) Grey muds and sands.—Met with chiefly near oceanic islands of volcanic origin.
   (*c*) Red mud.—Met with on the eastern coast of South America.
   (*d*) Coral-mud.—Met with near coral reefs.
2. *Globigerina-ooze.*—An abundant oceanic deposit not met with south of latitude 50° S.
3. *Radiolarian ooze.*—An oceanic deposit met with only in the Western and Middle Pacific.
4. *Diatomaceous ooze.*—An oceanic deposit met with only south of 50° S. latitude.
5. *Red and Grey Clays.*—The most abundant oceanic deposit.

The above names have been selected as indicating those elements which give the predominating character of the deposit. As a rule, when the débris of continents or islands, the dead shells of Foraminifera, the exuviæ of Radiolarians &c., the frustules of Diatoms, or red or grey clayey matter—when any of these have appeared to make up considerably more than one half of the specimen under examination, it has been called a shore-deposit, a *Globigerina*, Radiolarian, or Diatom ooze, or red or grey clay.

Sometimes it has been doubtful whether a specimen should be placed under one of the above heads or another, on account of the nearly equal ratio of constituents, or where one deposit overlies another of a different kind. In these cases the specimen has been placed under that head with which, on a general view, it has seemed to have most in common, or to which the surface-layer belonged, and a detailed description has been added in the list. A sixth kind of deposit or formation might have been added, to embrace those bottoms in which a great quantity of the peroxide of manganese occurs. This substance, in the form of nodules or concretions, of incrustations or in grains, has been found in nearly all sea-deposits and at all depths in more or less abundance. However, for the present, it has been considered best to treat of its occurrence separately, at the some time pointing out those regions where we have found it in greatest abundance.

A few remarks may now be made upon each of the kinds of deposits indicated.

1. *Shore-deposits.*—It has been found that the deposits taking place near continents and islands have received their chief characteristic from the presence of the débris of adjacent lands. In some cases these deposits extend to a distance of over 150 miles from the coast. Several varieties can be recognized amongst these shore-deposits.

(*a*) *Blue and Green Muds.*—In the great majority of cases the deposits near continents and large islands, containing the older and crystalline rocks, have been of a blue or green colour; the only exception appears to be the east coast of South America, where we have a red mud, to be presently referred to.

In from 100 to 700 fathoms these deposits are often of a green colour, due to the presence of green amorphous clayey matter, and dark and pale green glauconite particles.

Beyond 700 fathoms they are usually of a blue or dark slate-colour, having a thin upper layer of a red or brown. This red layer is a soft ooze, whilst the blue mud or clay beneath is very compact and tenacious.

Much amorphous clayey matter and fine particles of mica, quartz, and other minerals are found in all these deposits, the mineral particles increasing in size as we approach the land.

Down to 1500 fathoms, we have generally found that Pteropod, larval Gasteropod, and Lamellibranch shells were tolerably abundant, and that there were many of the shore forms of Foraminifera, as Textularias, Rotularias, Nodosarias, Uvigerinas, Lagenas, &c. Pelagic Foraminifera occur throughout the deposit, but not in such abandance as in a true ocean-deposit. The frustules of Diatoms and their broken parts are numerous. Manganese grains are found in many of the bottoms, usually in the deeper soundings. We have also found imbedded in these muds pieces of wood, fruits, portions of fruits, and leaves of trees. Large pieces of rock, as pumice and granite, and rounded pebbles also occur. Our soundings near the southern ice-barrier were muds of a blue colour, containing many granitic and other pebbles and blocks, mostly rounded, and many Diatoms, and resembled in most respects the deposits we found off the east coast of North America, Halifax to New York.

Beyond 1500 or 1700 fathoms, Pteropod and Heteropod shells are usually not found, and in 3000 fathoms hardly a Foraminiferous or other carbonate-of-lime organism remains.

Siliceous organisms occur at all depths, but at times their remains would seem to be completely removed.

These green and blue muds have been found to prevail in all the enclosed seas we have visited, as Arafura, Banda, Celebes, and China Seas, Inland Sea of Japan; and in all these the carbonate-of-lime organisms would appear to be removed from the bottoms in depths less by some 400 or 500 fathoms than on open coasts.

In the green muds from 50 to 700 fathoms we have found those beautiful casts of Foraminifera, Pteropods, *Echini*-spines, and other carbonate-of-lime organisms frequently in great numbers. These are of a dark green, pale green, and dirty white colour. In all cases where these green internal casts occur we have many glauconite grains in the bottom. Beyond 700 fathoms these casts seldom occur, and when they do they are very sparingly distributed; and the same may be said of the glauconite grains which accompany them. River-muds, in which Pteropods, Radiolaria, and pelagic Foraminifera are usually wanting, are included in these deposits.

The following are the localities in which we have found the blue muds (an * before the locality indicates that the glauconite casts and grains have been found there):—

* Off coast of Portugal.
„ Virgin Islands (?).
* „ Coast of North America, Halifax to New York.
„ Guinea, coast of Africa.
* „ Cape of Good Hope.
„ Antarctic ice-barrier.
* „ Australia.
* „ New Zealand.
* „ New Guinea and Philippines, and throughout the seas of the East-Indian archipelago.
* „ Japan.
„ East coast of South America.

The following are the depths of the soundings which have been placed under this head:—

Blue Muds.

fms.	fms.	fms.	fms.	fms.
1125	1700	1675	32	375
1290	1240	1800	1100	2225
1475	1350	1300	700	2050
1380	1340	2200	2800	2000
1800	1250	400	1425	1075
1000	2020	150	2550	2250
525	1750	140	2100	20
900	2500	75	700	2675
600	2325	39	90	1875
3875	1250	40	150	2225
2425				

Green Muds.

fms.	fms.	fms.	fms.	fms.
470	2200	400	129	37
560	290	10	255	152
80	120	70	100	245
75	650	800	705	565
100	950	580	185	775
150	1200			

(*b*) *Grey Muds and Sands.*—Near volcanic islands we have found that the deposits have a distinctive character, from the presence of the débris of volcanic rocks. The presence of pieces of pumice, scoria, &c. prevents this deposit having that clayey character so characteristic of the blue mud. The colour is generally grey, but occasionally is a black sand or a more or less slate-coloured mud. In some places the shells of oceanic organisms make up a large part of these muds.

Down to about 1500 fathoms we have Pteropod, Heteropod, and surface Gasteropod shells, and the shore forms of Foraminifera are common. Deeper than 1500 fathoms, Pteropod shells are rare or entirely removed. Pelagic Foraminifera are found at all depths; but occasionally they and the siliceous organisms are quite absent at a depth of little over 2000 fathoms, and then we have a clay or mud with many small particles of pumice, scoria, &c. Manganese appears to be intimately associated with some of these bottoms, especially where the débris of augitic lavas are present, as at Sandwich Islands, Canaries, and elsewhere. Off the Desertas, in 670 fathoms, all the dead shells, pieces of Polyzoa, &c. had a slight coating of this substance, and we have had indications of the same thing in even less depths. In 1100 fathoms off the Canaries some pieces of shell had rather a thick coating; and in 1575 fathoms, not far from this place, the dredge brought up a great quantity of a Gorgonoid axis deeply imbedded in or coated with this black oxide of manganese.

In some localities this deposit extends to a great distance from the islands, as at Hawaii, 200 miles or more.

The following are the depths of the soundings which we have classed as

Grey Mud.

fms.	fms.	fms.	fms.	fms.
670	1750	1675 (?)	20 to 100	500
1150	620	465	75	2050
930	1890	675	520	2875
1500	1525	260	630	2650
278	450	360	600	1525
630	1000	1100	1200	420
560	1125	50	2150	590
7	1070	150	2600	620
640	1000	600	1050	680

Occasionally a few casts of the Foraminifera have been observed of a red colour. These were usually very rough, and had not the delicate hues of the green glauconite casts. One very remarkable exception occurs:—off the Crozets there were (in 600 fathoms) many beautiful casts of the carbonate-of-lime organisms of a pale straw-colour. None of the glauconite grains were noticed in the same sounding or locality.

(*c*) *Red Mud.*—It has already been stated that the deposit along the east coast of South America, from Cape San Roque to Bahia, differed from the deposits found along the shores of other continents and large islands in being of a red colour. There can be little doubt but that this red colour is due to the presence of the ochreous matter carried into the Atlantic by the South-American rivers. There are reasons for thinking that the red colour of some of the deep-sea clays in this region of the Atlantic may have a like origin.

The soundings near the shore and in shallow water have a deeper red colour and contain larger mineral particles and fewer organic remains than those further from land and in deeper water. The mineral particles are chiefly quartz and mica.

In all these soundings there are many pelagic and other Foraminifera, Heteropod, Pteropod, larval Gasteropod, and Lamellibranch shells, Coccoliths, and Rhabdoliths. Siliceous organic remains, as of Diatoms and Radiolaria, are almost quite absent in these bottoms. In some of the shallower depths a few red-coloured casts of Foraminifera were observed; but these were rare, rough, and more or less imperfect.

The following are the depths of the soundings along this coast:—

fms.	fms.	fms.
1375	120	1200
500	32	1700
2050	400	1015
1650	1715	1275
675	1600	2150

(*d*) *Coral-Mud.*—This is a deposit found in the neighbourhood of coral reefs. It is characterized by a large quantity of amorphous calcareous matter, by the débris of coral reefs, by many large calcareous forms of Foraminifera, and by broken pieces of Polyzoa, &c. All the deposits about Bermuda are of this nature, extending from the edge of the reef down to a depth of 2500 fathoms. At 1000 fathoms the mud assumes a rose tinge; this deepens into a red colour with greater depth and the accompanying decrease of carbonate of lime and increase of clayey matter, until the coral-mud merges into the red and grey clays of the surrounding ocean. About Bermuda very few mineral particles were found. In some of the soundings to the S.W. of the island there were some small pieces of a green rock like those at St. Paul's Rocks, and probably serpentine. One or two pieces of quartz, or sanidin, a piece of mica, and a small piece of pumice (?) were also noticed. Dissolving away carbonate of lime in some of the shallower soundings only a trace of clayey matter remained with a perceptible rose tinge. No casts of the Foraminifera were noticed about Bermuda.

At the Virgin Islands, at Tongatabu, at Fiji Islands, at Cape York, Admiralty Islands, Honolulu, and Tahiti we also met with coral-muds. Except at Cape York, these muds appeared to exist as a narrow band around the land, and had usually a considerable admixture of clayey matter and mineral particles.

Where there was much clayey matter we found usually a few rough red casts of the Foraminifera.

The following is a list of the depths of the soundings included under coral-muds :—

At Bermuda.			At other places.		
fms.	fms.	fms.	fms.	fms.	fms.
2250	2100	1250	460	140	25
1820	1950	1575	390	210	100
950	2650	1500	625	610	40
430	1325	200	18	70	90
1375	1075	37	240	25	100
2450			315	16	
			255		

2. *Globigerina-ooze.*—After the deep-sea clays, this is the most abundant deep-sea deposit. It has occurred at all depths from 250 fathoms to 2900 fathoms. The *Globigerinæ*, which give at once the name and the chief characteristic to this deposit, are really found all over the bottom of the ocean. Even in our deepest clays, if the surface-layers be selected and all the amorphous matter be washed away, one or two shells of some variety of pelagic Foraminifera can usually be detected. By pursuing this method I have only failed on one or two occasions. They appear to be quite absent in the Arafura Sea. It is, however, when they occur in vast numbers that they form the deposit known by this name; at least such is the sense in which it is here used.

We did not find a *Globigerina*-ooze in any of the enclosed seas, in the Southern Ocean south of lat. 50° S., nor in the North Pacific north of lat. 10° N.

In the Southern Ocean only one small species of *Globigerina* was found in the surface-waters; but in the North Pacific many varieties of pelagic Foraminifera abound near the surface of the ocean.

In other parts of the preceding oceans, and in the other oceans we have visited, it occurs in irregular patches, being always present in the open ocean when we have depths of less than 1800 fathoms. Its presence or absence at depths beyond 1800 fathoms is, however, determined by conditions at present unknown. A number of varieties occur both as to colour and composition. Some specimens are nearly pure white, others have a rose-colour, and others are red or dark brown. The red and brown colour arises from the presence of the oxides of iron and manganese. In the white varieties the sediment, after dissolving away the carbonate of lime, is in some specimens abundant, in others not abundant, and is either of a red or slate-blue colour. We find the former colour to prevail in those soundings far from continents and large islands, and the sediment is not abundant except where pumice or scoria is present. The latter, or slate-blue colour, is found in those soundings more or less near continents and large islands; and it is suspected that this sediment has its source chiefly from the disintegration of these adjacent lands.

Mica, quartz, pumice, scoria, and other mineral particles are met with; but in those soundings furthest from land a little piece of pumice or scoria may be the only trace of mineral particles.

In some specimens there are very many remains of organisms with siliceous shells, as Radiolaria, Diatoms, and Challengerias; but in others these remains are almost entirely wanting. In three soundings in mid-Atlantic between the Canary and Virgin Islands, and in several soundings in the South Pacific, manganese in the forms of grains and nodular concretions is very abundant. As a rule, however, this substance occurs rather sparingly in *Globigerina*-ooze. In some instances we get little nodules of these bottoms, the shells as it were being run together by a siliceous cement. Many small pieces of cherty-like mineral also occur, which are angular and soft, and do not look as if they had been transported. Manganese nodules occurring in the *Globigerina*-ooze have often a nucleus of a yellow and green colour, in which *Globigerina*-shells can be seen; but their carbonate of lime has been entirely removed, and replaced by a silicate. There are reasons for thinking that these indications of flint (?) occur only in those samples where the siliceous shells of Radiolaria, Diatoms, &c. are wanting, and do not occur where these organisms are present. A reexamination of all the bottoms must be made before this statement can be definitely affirmed. Casts of Foraminifera occur very sparingly in *Globigerina*-ooze; in the purest samples not at all. In those with an admixture of clayey matter we have frequently one or two partial casts of a very rough character. In two soundings, Nos. 211 and 301, in the Pacific, we found the Foraminifera not only filled, but also coated with a red substance, so that we had both an internal and an external cast, the two being connected by little rods representing the foramina of the shell. In these soundings there was much clayey matter and disintegrating pumice and scoria.

In a few soundings in the Pacific, as No. 304, we have had a *Globigerina*-ooze on the surface of the bottom, and a foot beneath a nearly pure red or brown clay. Again, as in Nos. 268 and 307, we have the reverse arrangement, a clay occupying the surface, and the deeper layers having many *Globigerinæ*. In all these cases the surface-layer has been normal with the other soundings in the same region as to depth. In the first case we might bring in elevation to account for the

Globigerina-ooze overlying the red clay, or we might suppose that chemical changes are going on in the deeper layers which remove the carbonate of lime. In the second case we may account for a red clay overlying a deposit with many *Globigerinæ* in it by supposing a depression of the bottom after the latter had been laid down; or we may believe that agencies are now removing carbonate of lime from the surface-layer, and that these were not active in some past time.

This deposit occurs, in one sounding, in the Pacific at a depth of 2925 fathoms in mid-ocean. In the eastern part of the Atlantic it occurs also at great depths.

The following is a list of the depths at which we have found a *Globigerina*-ooze:—

Atlantic Ocean.

fms.	fms.	fms.	fms.	fms.	fms.
1090	1900	2200	1350	1425	2275
1525	1950	1675	900	1650	2475
2250	2325	1675	2025	2300	2200
2225	1420	1240	2660	2300	2150
1945	2575	1000	2675	2400	2275
1975	2450	2500	2400	2400	2050
1150	2475	2275	1500	2075	1900
2300	2175	1850	1900	780	2025
2025					

Southern Ocean.

fms.	fms.	fms.	fms.	fms.	fms.
1900	1570	1375	1600	1800	2150

Pacific Ocean.

fms.	fms.	fms.	fms.	fms.	fms.
1974	1350	1675	2925	1915	1500
1100	1450	2000	2425	1600	1825
275	1700	1100	1940	2025	1775
400	1400	1850	2075		

3. *Radiolarian Ooze.*—Organisms with the siliceous skeletons abound in the surface-waters, and apparently also in the deepest waters, of all the oceans and seas we have visited [*]. The skeletons of these organisms are found in all, or almost all, the sea-bottoms. Even in those cases where at first sight they would seem to be quite absent, a more careful examination (by dissolving away a large quantity of carbonate of lime where this exists, and examining the sediment by careful washing in the case of clays, &c.) will usually reveal a Radiolarian skeleton, a Diatom frustule, or broken portions of these.

It is, however, only in some limited areas that these exuviæ rise into such prominence as to be characteristic of the deposit taking place. Such is the case in the Antarctic, where we have a Diatom-ooze, and in the Western and Middle Pacific, where we have the above deposit.

---

[*] They are, however, much more numerous in the Pacific than in the Atlantic, especially in the equatorial waters.

Our deepest sounding (4475 fathoms or 4575, see p. 504) was a Radiolarian ooze; with the exception of a little amorphous matter, manganese particles, a few yellow cherty-like particles, and some pumice pieces, this bottom was entirely composed of the exuviæ of organisms with siliceous skeletons—as Radiolaria, one or two Diatoms, and some organisms which seem to be undescribed (Challengerias), but which are numerous in the deeper waters of the Pacific (see notes on surface animals, p. 536).

A section of about 3 inches came up. The upper two were of a red colour, due to the presence of much manganese; the lower one was a pale straw-colour, and contained relatively few manganese grains.

In our trip from the Sandwich Islands to the Society Islands we again met with Radiolarian ooze. Between 7° and 12° north of the equator we came on a patch represented by four soundings, some of these containing not a single *Globigerina*; then just on the equator, in two soundings, one at a depth of 2925 fathoms, we got a *Globigerina*-ooze containing a good many Radiolaria. Between 2° and 10° south we again had a patch of Radiolarian ooze represented by three soundings, and containing only a few pelagic Foraminifera or their broken parts. The occurrence of this patch of *Globigerina*-ooze in the position indicated (see map, Plate 20), and the comparative or total absence of the *Globigerina*-shells in the deposits a little to the north and south of it, is sufficiently curious and significant. It will be well to note that, in the *Globigerina*-patch, manganese and other mineral particles are much less abundant than in the adjacent Radiolarian. Note also the presence of the south equatorial current and the dip of some isotherms over the *Globigerina*-patch. One or two soundings to the east of Japan might have been classed under this head; but in them the siliceous remains do not make up over one third of the sample in bulk. Generally it may be said that in the Western and Middle Pacific the siliceous remains of Radiolaria and Diatoms are abundant in the deposits, whereas in the South Pacific and Atlantic they are much less so, or absent in the bottoms.

The following are the depths of the soundings placed under the head of Radiolarian ooze:—

fms.	fms.	fms.
{ 4575	2700	2600
{ 4475	2900	2350
2750	2250	2750

4. *Diatomaceous Ooze.*—South of the latitude of the Crozets, on our southern trip, we found Diatoms abundant, both in the surface-waters and in the bottom.

About the Crozets, Kerguelen, M‘Donald's Islands, and close to the ice-barrier, the frustules of these organisms were very abundant in the soundings, but were masked by much land-débris. Between the parallels of 53° and 63° S., *i. e.* between the north edge of the ice and the latitude of M‘Donald's Islands, we got in three soundings a pale straw-coloured deposit, composed principally of the frustules of Diatoms and their broken-down parts. In addition, they contained a good many Radiolarian remains, a few specimens of one small species of *Globigerina*, a few particles of mica, quartz, and granitic pebbles, also a little amorphous blue clayey matter. No manganese particles were noticed. The one of these soundings which is nearest to the ice contains much amorphous clayey matter and larger mineral particles than the other two. When dried this deposit is of a white colour, and is very light.

The following are the depths of the soundings referred to above:—

fms.	fms.	fms.
1260	1975	1950

5. *Red and Grey Clays.*—By far the most abundant oceanic deposits are the deep-sea clays. These are of a grey, red, or dark chocolate-colour, and are found at depths greater than 2000 fathoms. The red and chocolate-colours of many of these clays is due to the presence of the oxide of iron in the first and of oxide of manganese in the latter instance. Most of them contain some carbonate of lime in the form of *Globigerina*-shells; in one or two instances, however, I have not been able to find a single shell, nor has acid caused the least bubble of effervescence. The remains of siliceous organisms occur also in great numbers in the clays of some regions—so much so that, as I have stated, some of those soundings in the North-west Pacific which have been classed as clays might have been called Radiolarian ooze. In most places, however, they are nearly or quite absent. These clays are not amorphous in the true sense of the word—not amorphous in the sense in which a chemical precipitate is amorphous. They all contain small white and other coloured mineral particles in great abundance—exceedingly small particles, so as to be recognized only under the high powers of the microscope. They contain amorphous matter, it is true; but it is doubtful if this ever makes up so much as a half of any sample in bulk. They also contain larger mineral particles, as quartz, mica, pumice, scoria, peroxide of manganese, and other mineral particles. Quartz and mica particles appear to be present only in some localities, as the North Atlantic and elsewhere. Peroxide of manganese is perhaps always present in the form of grains or nodules, sparingly distributed in some regions, in others making up nearly a half of the deposit or formation.

Pumice (the common felspathic or the highly vesicular augitic variety) and scoria appear to be universally distributed over the bottom of the ocean, and to be abundant in most of the deep-sea clays and present in them all. In those clays furthest from continents and islands sharks' teeth, ear-bones of whales, other bones of whales, and bones of turtles (?) are very frequently found, all these having usually a more or less thick coating of peroxide of manganese. The following are the depths at which we have found these red and grey clays:—

Atlantic.

fms.	fms.	fms.	fms.	fms.
2740	2385	2700	2650	2700
2950	2675	2600	2500	2750
2750	3000	2475	2360	2700
2800	2975	2600	2575	2350
3150	3025	2850	2850	2275
2720	2800	2675	2875	2550
2575	2960	2800	2750	2650
2435	2850	2650	2750	

Southern and Pacific Oceans.

fms.	fms.	fms.	fms.	fms.
2600	2450	2575	3125	2325
2600	2325	2800	2025	2385
2600	2300	2900	2850	2450
2900	2475	2775	2950	2375
2650	2450	2050	2875	2250
2325	2500	2530	2775	2335
2450	2425	2900	2225	2270
2440	3900	2300	3000	2400
2275	3600	2350	2900	2600
2550	2900	2900	2610	2550
2650	2300	2740	2350	2300

The Manganese in Deposits.

The peroxide of manganese, in the form of minute grains, concretions, nodules, aggregations, or incrustations, occurs widely distributed in ocean-deposits. It has been met with most frequently in the deep-sea clays; indeed it seems to be present in all of them, sparingly in some localities, abundantly in others.

It is, however, not confined to these clays; it has been found in most of the other deposits and at all depths greater than 500 fathoms. In the *Globigerina*- and Radiolarian ooze and in the clays it usually assumes the forms of minute grains, pellets, and nodules. In those bottoms to which it gives a chocolate-colour, the higher powers of the microscope show small, round, red-brown grains of manganese, often with a dark spot in the centre.

The nodules vary from little pellets to masses of a large size and of several pounds in weight. In some regions every thing at the bottom, even the bottom itself, would appear to be overlaid by and impregnated with this substance. In the foregoing list, as at No. 318 and elsewhere, some of the nodules have been described with a little detail. The varieties which are most commonly procured may be here mentioned:—

Nodules of a black-brown colour throughout, the manganese being laid down in concentric layers, which are evident from their enclosing lines of red clay.

Nodules having a nucleus of pumice which is surrounded by concen-

> tric layers, the original nucleus being often very deeply impregnated by spider-like ramifications of the manganese, or nearly the whole pumice may be replaced by manganese. When pieces of bone have formed the nucleus we have much the same state of things. The compact bone of the tympanics of cetaceans does not, however, appear to alter so rapidly as other bone; and hence it may be that we get ear-bones in such great numbers.

Sharks' teeth of all sizes (one was 4 inches across the base) are frequent, and are sometimes surrounded by concentric layers of nearly an inch in thickness. A siliceous sponge (*Farrea*) was found imbedded in two inches.

A mass of red clay may occupy the centre of the nodule. The nucleus is occasionally a mottled yellow-and-green substance, with agate bands in some parts, and *Globigerina*, the carbonate of lime being replaced by silicate in these last. This nucleus can be cut with a knife, like new cheese, or it is hard and brittle, breaking with a conchoidal fracture.

Large flat aggregations occur which seem to have been formed on hardened flat portions of the bottom.

The *Globigerina*-shells and Radiolaria are at times covered by small specks of the manganese; and in the former these are deposited in the substance of the shell.

In several soundings and dredgings to the south-west of the Canaries we got very many large pieces of a branching Gorgonoid which were deeply coated and impregnated with manganese. This was in a depth of from 1100 to 1575 fathoms.

In 670 fathoms, off the Desertas, the dead shells, pieces of coral, Polyzoa, &c. were all coated with a thin film of the peroxide of manganese; and we have had indications of the same thing in still shallower water.

In some of the Radiolarian oozes, and in other deposits, we have found the manganese more abundant in the upper layers than in the lower, and *vice versâ*.

The following are the localities where we have met the manganese in greatest quantities:—

Off the Canary Islands.

Mid-Atlantic, between Canary and Virgin Islands.

South-west of Australia.

North and south of the Sandwich Islands.

North of Tahiti.

Generally in the South Pacific in our course between Tahiti and Valparaiso (see Map, Plate 20).

Further observations may show that manganese abounds in those places where we have much of the débris of augitic lavas.

Abyssal Rhizopods (Bathybius).

The manganese nodules, sharks' teeth, &c. which we got in our deepest trawlings have very frequently small branching tubes, composed of clay and sandy particles, running over their surfaces. These belong to a Rhizopodal organism. The sarcode which fills these tubes contains many large brown pigment-cells, and small bioplasts are collected in clumps at distances along the length of the tube, or are scattered throughout it.

Tubes of a similar nature, but composed of pieces of *Globigerina*, Radiolaria, &c., would appear to be rather abundant on some of the oozes, and to run irregularly over the bottom.

In the clays we always get some arenaceous forms of Foraminifera when there has been a successful haul with the trawl. Their shells are made up of pieces of manganese, clay, and small mineral particles, and they contain the same kind of sarcodic substance as the tubes above referred to.

An attached calcareous form (c. f. *Carpenteria*) has been found in rather deep water, and Biloculinas, Nodosarias, Triloculinas, and other forms have been frequently procured alive. These last have orange-coloured pigment-cells, in which respect they resemble surface Rhizopods. A living specimen of *Orbulina* or *Globigerina* undoubtedly from the bottom has not yet been met with.

In the early part of the cruise many attempts were made by all of the naturalists to detect the presence of free protoplasm in or on the bottoms from our soundings and dredgings, but with no definite result. It was undoubted, however, that some specimens of the sea-bottom preserved in spirit assumed a very mobile or jelly-like aspect, and also that flocculent matter was often present.

Mr. Buchanan determined that the flocculent matter was simply the amorphous sulphate of lime precipitated by spirit from the sea-water*. Subsequently a number of experiments were made upon the behaviour of this amorphous precipitate when precipitated with different quantities of spirit and when treated with colouring-solutions. The precipitate was also examined alone and mixed up with some of the ooze. The ooze was examined at the same time, and in the same manner, but without having been treated with spirit. The results were shortly these:—

When sea-water is treated with twice its volume of spirit or less, nearly the whole of the amorphous precipitate assumes the crystalline form in a short time.

When treated with a great excess of spirit the precipitate remains amorphous, and assumes a gelatinous aspect.

This gelatinous-like sulphate of lime colours with the carmine and iodine solutions, and when mixed with the ooze has, under the microscope, the appearances so minutely described by Häckel.

The ooze washed with distilled water, or taken just as it comes up, and treated in the same manner with colouring-solution, does not show these appearances. The jelly-like aspect and the matter coloured with carmine can always be removed from the spirit-preserved specimens of the ooze by treating with distilled water.

---

* See Mr. Buchanan's report.

In all cases the jelly-like or mobile aspect of the oozes is found to be due to the presence of the flocculent precipitate from the sea-water associated with the ooze.

No free albuminous matter could be detected.'

When it is remembered that the original describers worked with spirit-preserved specimens of the bottom, the inference seems fair that *Bathybius* and the amorphous sulphate of lime are identical, and that in placing it amongst living things, the describers have committed an error.

ORIGIN OF DEEP-SEA CLAYS. RELATIVE RATE OF DEPOSITION OF DEPOSITS. CONCLUSION.

The very wide distribution of pumice, vesicular lava, or light scoriæ has been already alluded to. Some of the bottoms which have been classed under the head of clays, as 2900 fathoms south of Tongatabu, are largely made up of pumice in a fine state of division. Pumice or vesicular lavas have, in short, been found in all the kinds of deposits, most abundantly in the vicinity of volcanic islands and in the deep-sea clays. It appears to be universally present, and its disintegration is most probably the chief source of the clayey matter found in oceanic deposits. North of the Sandwich Islands we for several days got small pieces of pumice floating on the surface, most of the pieces being covered with a fungoid growth. In this connexion it may be well to remember that Mr. Bates states somewhere that he found pumice rather common, floating on the surface of the Amazons, over a thousand miles from the nearest volcanic region. Many instances are given by Sir Charles Lyell of volcanic ashes having been transported to great distances by the wind.

At Honolulu Mr. Green informed me that *Pele's hair* had been picked up in his garden there after an irruption of Kelauea in Hawaii, a distance of about 180 miles from the crater. If there be an ash after the carbonate of lime is removed by carbonic acid or other agent, this will be another source of the clay.

Mr. Buchanan has determined in the clays the presence of copper, cobalt, and nickel, in addition to iron and manganese. Remembering this, one is tempted to suggest the presence of meteoric or cosmic dust in these deposits.

When we have had a good haul from a red-clay bottom, when the bag comes up full of nodules, tympanic bones, and sharks' teeth, we cannot resist the idea that we are dealing with things of a vast antiquity, and that we have evidences of a very slowly accumulating deposit. When there has been no reason to suppose that the trawl has sunk more than one or two inches in the clay, we have had in the bag over a hundred sharks' teeth and between thirty and forty ear-bones of cetaceans; some of these have been imbedded in over an inch of the manganese, arranged in concentric layers, while others have had just a trace of manganese on them, or none at all. We have every reason to suppose that the aggregation of the manganese around these relics is a very slow process, and that consequently the occurrence of these deeply imbedded and recent teeth and tympanics in the same surface-layers argues strongly in favour of an exceedingly slow rate of deposition. These vertebrate remains are most abundant where the manganese abounds, but occur also in the red and grey clays, especially in those the furthest from the land, and where we may suppose the rate of deposition to be reduced to a minimum.

In the *Globigerina*, Radiolarian, and Diatom oozes we have found during the whole cruise only one or two shark's teeth and perhaps one tympanic bone. In shore-deposits they were even more rare. These facts, taken with others that will at once suggest themselves, go to show, as might be expected, that the shore-deposits accumulate faster than the organic oozes, and these last faster than the deep-sea clay. The organisms in our Radiolarian ooze appear to resemble very closely and in their relative proportions those described from the Barbadoes earth. Those described from the Oran deposit in Algeria are very like those in the blue muds taken along the course of the Japan stream. The *Globigerina*-oozes which we get in shallow water resemble the chalk much more than those in deeper water, say over 1000 fathoms. It is possible that deposits similar to those taking place in deep water, far away from the great continental anticlines, may never have been elevated into dry land.

In conclusion, large quantities of the various bottoms have been stored with a view to future work, and a large amount of material bearing on the subjects treated of in this Preliminary Report have been accumulated. When these come to be carefully examined and compared, with the aid of appliances and conveniences not to be had on board ship, many of the statements herein made may require to be altered and amended, and other facts and relations, more curious and interesting than any hinted at, may be revealed.

2. Preliminary Report on some Surface Organisms and their relation to Ocean Deposits.

Throughout the cruise of the 'Challenger,' and especially during the past two years, tow-nets have been dragged through the surface and deep waters of the sea on every possible occasion. The contents of the nets, so far as known, have been carefully noted, and many hundreds of preparations have been made with the view of illustrating the organisms occurring in different regions and at various depths. Many new animals have been discovered, and many curious relations brought to light. It is not now possible to give any descriptions or to report fully with any success or satisfaction on such an extended series of observations.

A few remarks on those organisms which have an interest in relation to the deposits taking place at the bottom of the sea is all that will be attempted. Soon after the arrival of the Expedition at home I hope to be able to give a more complete report on surface organisms.

Diatoms.—In the Southern Ocean, south of Kerguelen, in the Arafura Sea, off the coasts of Japan, New Guinea, North America, and in enclosed bays and river-deltas, in short, wherever the specific gravity of the sea is low from an admixture of fresh water, we have met with very many Diatoms on the surface. Taking the maps which Mr. Buchanan has prepared, showing areas of low specific gravity, and comparing these with the records of the occurrence of Diatoms in great abundance, it is significant how often these agree. Again, excepting the area of the Diatom-ooze, those places where Diatoms are abundant, and where the specific gravity of the water is low, coincide generally with the areas where the blue muds are found, *i. e.* along the continents and great islands. It may be stated generally that close to these shores we have in the surface-waters organisms more or less distinct from those occurring in the open sea. Besides many forms of Diatoms, the true *Noctiluca*, several *Peridinia*, larvæ of Annelids, and Mollusca, Hydroid Medusæ are more or less characteristic of these shore waters. In the Antarctic, in the Arafura Sea, at Hongkong, off Japan, and elsewhere the tow-nets were frequently filled with a yellow slime in a short time, which consisted chiefly of Diatoms. In the Southern Ocean, as has been stated, the Diatoms form a peculiar deposit. In other deposits they are at times also well preserved, but occasionally are either completely masked by shore-débris or removed from the bottom.

In the open ocean, in the region marked out by the north edge of the N.E. trade-wind and the south of the S.E. trade, small forms of Diatoms do not occur in any numbers. They are represented, however, by three large species, which are undescribed so far as is known. Mr. Wild has figured two of these in Plate 21. These organisms have an exceedingly thin coating of silica and are true Diatoms, though they have been confounded with *Noctiluca*. The nuclei of both these forms are highly phosphorescent, and to them the diffused phosphorescence of the ocean within the tropics is generally due. A third large Diatom has a cylindrical shape and a much thicker coat of silica, and is not phosphorescent. These three forms are highly characteristic of the presence of tropical oceanic waters. The provisional generic name of *Pyrocystis* is proposed for the organisms figured in this Plate.

Coccospheres and Rhabdospheres.—These minute organisms, which are regarded as algæ, have been found all over the ocean, except south of the latitude of Kerguelen and in some of the enclosed seas. Their remains, in the forms of Coccoliths and Rhabdoliths, make up a very considerable portion of the bottom in some of the *Globigerina*-oozes. They are always associated with the pelagic Foraminifera; and when these are absent from the bottom so also are the Coccoliths and Rhabdoliths.

Pelagic Foraminifera.—All the observations which have been or may yet be made upon these animals will be collected at the end of our cruise, and published with those which have been made by Professor Wyville Thomson. It is here proposed to record shortly those results which it is believed have already been attained.

Calcareous Foraminifera have been found in the surface-waters of all the oceans and seas we have visited, excepting the Arafura and Japan inland seas.

In the tropics they are most abundant, both as to species and numbers, and are more numerous in the open ocean than near land.

Our tow-nets have perhaps in no single instance been dragged down to 200 fathoms without yielding some forms. At times they occur in vast numbers on the surface, and with a bottle can be picked up from a boat. In one specimen thus procured the sarcode of the animal was found thrown out into bubble-like extensions between the spines of the shell, and over these expansions of the sarcode and along the spines the pseudopodia moved freely and rapidly. Mr. Wild has figured this specimen in Plates 22 and 23, and Professor Wyville Thomson proposes to describe it under the generic name of *Hastigerina.*

This is the only instance in which we have seen one of these creatures fully expanded; however, those taken in the net can, when the ship is steady, be got to expand partially. Almost always when they come up in the net the sarcode is found to adhere to and surround closely the outside of the shell, so much so that the pigment-cells and oil-globules obscure the shell, especially in the Pulvinulinas.

Those species without spines apparently throw out bubble-like expansions of the sarcode in the same manner as *Hastigerina.* They have, however, been seen only partially extended.

The sarcode matter of these organisms includes very many orange-coloured pigment-cells and oil-globules, the shape and size of these varying with the species. The sarcode has also many small bioplasts scattered through it, which quickly colour with carmine. These are generally found congregated in the smaller chambers of the shell when the animal is at rest.

About a dozen species of these organisms have been found on the surface; some are more or less tropical, others extend into the region of the westerly winds north and south, and one species is found in the Antarctic Ocean.

The shell of the species represented in the Plate has been observed only once from the bottom, and then only in a broken state. This is to be accounted for by the fact that the shell is exceedingly thin, delicate, and fragile.

The specimens of these Foraminifera taken in the surface-net are of all sizes, from the smallest ones to those which have been described with an exogenous growth. Species only occur on the bottom in those places where they are found on the surface. These organisms are found in vast numbers on the surface over regions where there are only a few traces of them or their broken parts on the bottom.

No living specimen of a *Globigerina*, an *Orbulina*, a *Pulvinulina*, or of the new genera found on the surface, which undoubtedly came from the bottom, has yet been met with.

The foregoing observations appear to justify the opinion that these organisms live only in the surface and subsurface waters of the ocean. The most potent agent concerned in the removal of these shells from the majority of the deep-sea deposits is very likely that suggested by Professor Wyville Thomson, viz. carbonic acid; yet there may be others. Why these shells should be almost entirely absent in some places at a depth of 2000 fathoms, and be abundant in some other few places at a depth of 2900 fathoms, has still to be explained. The tow-net seemed to show that they were as numerous in the surface-waters of the one region as of the other.

Two varieties of large cells are occasionally noticed in the pelagic Foraminifera, not unlike the reproductive cells which have been described as occurring in some Infusoria.

Radiolaria.—Radiolaria polyzoa, Acanthometræ, or Polycystinæ occur almost universally in the surface-waters of the ocean. As has been stated, they (in a few places in the Western, Northern, and Middle Pacific) make up a large or principal part of the deposits at the bottom. In very many places they appear to be nearly or quite absent in the bottoms. In some *Globigerina*-oozes they are present in considerable numbers, in others they cannot be detected. What agents are concerned in the removal of these organisms is at this time a matter of conjecture.

Deep-Sea Rhizopods.—In April 1875 a plan of sending down tow-nets to a great depth was adopted. These were either attached to the dredge and trawl-lines, or sent down separately to a depth of 2000 fathoms or more. This method has been repeatedly practised since, and with these results.

On every occasion organisms were found in the deep nets which had not hitherto, nor have since, been observed in the nets used near the surface. These appear to have a wide distribution, as the same forms have been taken in the deep nets in the North, Middle, and South Pacific, whilst the surface organisms have varied in these regions to a considerable extent. These organisms are:—

Many small crustaceans, usually of a bright orange-colour—Copepods, Amphipods, and Cypridinas principally. Many large-sized Radiolaria, resembling in most respects those forms described by Häckel under the generic name of *Calodendrum*.

Many other Rhizopods, with more or less flask-shaped or bivalved siliceous shells, which are undescribed, so far as is known.

Mr. Wild has figured six of these last in Plate 24; for the sake of convenience we have been accustomed to call the organisms Challengeridæ. This provisional name will be retained if it be found that these organisms are new to science and universally distributed in deep water.

The shells of all have an exceedingly beautiful tracery, a fenestrated appearance often, which was at first supposed to be due to perforations of the shell, but which a closer examination shows to be caused by pit-like depressions. Some have only one, others have several openings through which the sarcode flows. The sarcode of all these deep-sea Rhizopods has many large black-brown pigment-cells. Small bioplasts are scattered through the sarcode. These collect into capsular-like clumps when the animal is at rest, and are quickly coloured by carmine. At times these Challengeridæ come up with a good deal of the sarcode outside of the shell; and two specimens have been seen to throw out elongated pseudopodia.

I should think that not less than fifty species of these organisms have been taken in the deep nets already. They all resemble more or less those forms drawn by Mr. Wild. It will be interesting to learn if future investigations will show these organisms to be present in the deep waters of the Atlantic as well as the Pacific. In the Radiolarian oozes the remains of these Challengeridæ make up a considerable portion of the deposit, and in some other deposits of the North-west Pacific they are well preserved. In the majority of bottoms, however, they appear to be quite absent.

Pteropods, Heteropods, Pelagic Gasteropods.—Species of these orders occur everywhere in the surface-waters of the ocean. Their shells make up a large portion of some deposits in shallow water, where there is relatively little land-débris.

In depths less than 1500 fathoms they abound; deeper than this they become more and more rare. At 2000 fathoms and deeper the only trace of these shells in the deposits is an occasional *Diacria* or *Ianthina* of a large size.

Those shells which are thin and delicate, as *Atlanta*, *Carinaria*, and *Styliola*, disappear first from the bottoms.

GENERAL REMARKS.

Everywhere we have found life abundant in the surface and subsurface waters of the ocean. If living creatures are small in number on the surface, the tow-net will usually yield many forms if dragged at a depth of 100 fathoms or more. We have not met with any really barren regions. Our observations appear to show that there are several regions of the surface of the ocean, each of which is characterized by a number of peculiar organisms:—

1. A region roughly marked out by the northern edge of the N.E. trade-wind and the southern edge of the S.E. trade-wind.

2. A region lying along the coasts of great islands and continents, where we have usually a mixture of fresh and salt water.

3. A region in the Southern and Antarctic Oceans south of the latitude of 50° S.

In all depths less than 1500 fathoms there would seem to be a direct relation between the organisms occurring on the surface and the deposits taking place on the bottom. Where we have Diatoms on the surface, there we have their frustules on the bottom. Where we have *Globigerina* and Pteropods &c. on the surface, there also we get their dead shells or broken parts of them; and so also for the Radiolaria, Coccospheres, and other organisms. In some areas within the depths referred to we occasionally do not find the remains of some of the surface organisms so numerous as we should expect. In these cases, however, I suspect they are rather masked or obscured by an abundance of shore débris than removed from the deposit.

When we consider the specimens of the bottom from depths greater than 1500 fathoms, the relation is by no means so constant. It still holds good that when pelagic Foraminifera, Pteropods, Diatoms, Radiolaria, or Coccoliths are found on these bottoms, the same varieties of each of these are found on the surface; but perhaps in the majority of bottoms, in depths greater than 1500 fathoms, the exuviæ of some or all of the organisms found on the surface are partially or wholly absent. When these have been carefully reexamined, the results tabulated and compared with other observations recorded at the same place, it is likely some light will be thrown upon the subject.

3. Preliminary Report on Vertebrates.

Of the Vertebrate animals collected during the cruise, the chief interest is very naturally attached to those fishes on which our special investigations might be expected to give some information. Many specimens have been taken in our trawlings and dredgings. Other than the British Museum Catalogue, we have with us no literature on this subject. Many of the specimens which we regard as new may be described, and some of those which are believed to be identical with described species may turn out to be distinct; therefore for the present it is considered best to give a list of the fishes, with the determinations which were made at the time of their occurrence, and not to cumber this Report with descriptions.

Besides the fishes taken in the trawl and dredge, many small larval and adult forms have been obtained in the tow-nets. These last have chiefly been preserved as microscopic preparations. In every case notes have been taken at the time the specimens were procured, and all have been labelled and preserved with great care.

In the following List the depths to which the trawl had been down are given. Of course it is not asserted that the specimens came from these depths; indeed we know that many of the Sternoptychidæ and Scopelidæ are surface creatures.

It will be seen from the list that all the fishes taken in the trawl or dredge have been relegated to known families. The definitions of some families will require to be altered in order to admit some of the new forms; but it is not thought that a new family will require to be established.

There are many new genera and species. The list includes the dredgings in all the depths greater than 100 fathoms. If we had given only the trawlings in depths greater than 500 fathoms, all the shore forms which appear in the list would have been eliminated. Our dredgings and trawlings in less than 100 fathoms do not once give a specimen of the species so characteristic of the hauls in deep water.

The deep-sea and oceanic forms belong to very few families.

Sternoptychidæ.

These occur at 40 stations, and over a hundred specimens have been taken. Besides those from the trawl, small species have continually been taken in the nets in warm regions. South of the latitude of 50° S. we did not get a single species of this family.

Many of the pelagic species occur both in the Atlantic and Pacific Oceans, *i. e.* identical species.

Macruridæ

occur at 24 stations, and about one hundred specimens have been taken. They have been met with in all latitudes, and most frequently in depths between 200 and 1000 fathoms.

In this family we have many species which cannot be referred to existing genera. These fishes were almost always blown out and at times even burst when taken from the bag of the trawl. Some of the species appear to be universally distributed.

Ophidiidæ

occur at 18 stations, and 20 specimens have been taken. These fishes would seem to inhabit deeper water than the Macrurids, as they have in most cases been present in the trawl when it has been down to depths greater than 1000 fathoms. All of them appear to be undescribed, excepting *Bythites fuscus* (?). One specimen is quite blind; in another, which is semitransparent, the eyes are represented by small black dots. These fishes are apparently universally distributed.

Scopelidæ

occur 24 times, and 41 specimens have been taken. Many of these are truly pelagic fishes, while others have characters which mark them out as deep-sea. The majority of the forms cannot be referred to existing genera or species. Perhaps the most curious fish which we have obtained belong to this family. Two or three species have the upper rays of the pectoral fins greatly elongated, these rays being much longer than the fish in some cases. These rays arch over the head, and when erected simulate in a wonderful way Umbellularias, Virgularias, or Crinoids. Another species has a large white (phosphorescent?) organ situated on the head between the eyes.

These fishes have occurred in all regions, and when the trawl has been down to depths varying from 255 to 2385 fathoms.

Stomiatidæ

occur at 13 stations, and 15 specimens have been taken. These have been present only when the trawl has been down in deep water, and all have more or less deep-sea characters. There are two or three new generic forms, and new specimens of *Malacosteus* and *Echiostoma* have been secured.

Pediculati

occur at 7 stations, and 7 specimens have been taken. A *Chaunax* from 360 fathoms at the Fijis appears to be identical with that described from the sea off Madeira as *Chaunax pictus*. The other fishes of this family all belong to the same little group with *Melanocitus*, *Oneroides*, and *Ceratias*. One, which I propose to describe under the name of *Ceratias uranoscopus*, came up from 2400 fathoms in the North Atlantic, the only living thing in the dredge on this occasion.

Halosauridæ.

Halosaurus Owenii occurs at 5 stations, and 5 specimens have been taken. These seem all to be referable to the described species, and occur both in the Atlantic and Pacific.

Notocanthi.

One specimen was taken off the coast of Japan. It is a new species.

Murænidæ

occur at 10 stations, and 20 specimens have been taken. This family in our deep-water hauls is represented by *Nemichthys* and *Synaphobranchus*. The *Nemichthys* in the Atlantic is identical with the one described (*scolopacea*). One taken in the Pacific is generically distinct.

All the specimens of *Synaphobranchus* can, I think, be referred to the species described (*pinnatus*). They have occurred widely both in the Atlantic and Pacific, and generally with the Macrurids.

Trachinidæ.

A species referable to the genus *Chænichthys*, but with deep-sea characters, occurred in one of the deep hauls in the Southern Ocean.

Only one small specimen of the Sphyrænidæ and one of the Trichuridæ have been taken during the cruise.

We have while at sea captured only two species of sharks. One occurs widely distributed in the Atlantic and Pacific; the other was taken off the coast of Japan.

Whenever the ship has been at anchor, and wherever possible, collections have been made of Fishes, Amphibians, Reptiles, Birds, and Mammals. Collectively these now form a large collection. They have been preserved as skins, spirit specimens, and skeletons, and all with a view to future work. In the former three classes we have met with a good many new species. In Birds we may have some new species. In Mammals it is not likely we have any new species except amongst the Cheiroptera.

Of the Petrels and Penguins we have very extensive collections, both as skins and spirit, chromic acid, and other preparations.

Two or three skeletons of very large specimens of the Sea-Elephant have been preserved, and many specimens of the Southern Seals.

List of the Fishes obtained in Trawlings and Dredgings by H.M.S. 'Challenger' in the years 1873, 1874, *and* 1875.

Atlantic Ocean.

Station.	Specimen.	Number.	Depth.	Locality.	
				Lat.	Long.
			fathoms.		
1.	*Sternoptyx diaphana*	1	1127	41° 57′ N.	9° 42′ W.
4.	*Mora mediterranea*	1	600	36 25 N.	8 12 W.
	Coryphænoides	2			
5.	Coryphænoides	1	1090	35 47 N.	8 23 W.
	Halosaurus Owenii	1			
	Black Scopelid	1			
22.	Small black Sternoptychid	1	1420	18 40 N.	62 56 W.
23.	*Stomias boa*	1	450	Sombrero Island.	
	Small black Sternoptychid	1			
40.	*Sphyræna* probably (mutilated)	1	2675	34 51 N.	68 30 W.
60.	*Stomias boa*	1	2575	34 27 N.	58 56 W.
	Maurolicus	1			
61.	Sternoptychids	3	2850	34 54 N.	56 28 W.
63.	*Halosaurus*	1	2750	35 29 N.	50 53 W.
	Stomias, n. sp.	1			
	Small Sternoptychids	2			
68.	*Maurolicus*	1	2175	38 3 N.	39 19 W.
89.	*Ceratias uranoscopus*, n. sp.	1	2400	22 18 N.	22 2 W.
92.	Small Sternoptychid	1	1975	17 54 N.	24 41 W.
101.	*Scolopacia*	1	2500	5 48 N.	14 2 W.
	Stomiatids	2			
	Maurolicus	1			
	Argyropelecus	1			
104.	*Chauliodus Sloani*	1	2500	2 25 N.	20 1 W.
	Bythites fuscus, c. f.	2			

Atlantic Ocean (*continued*).

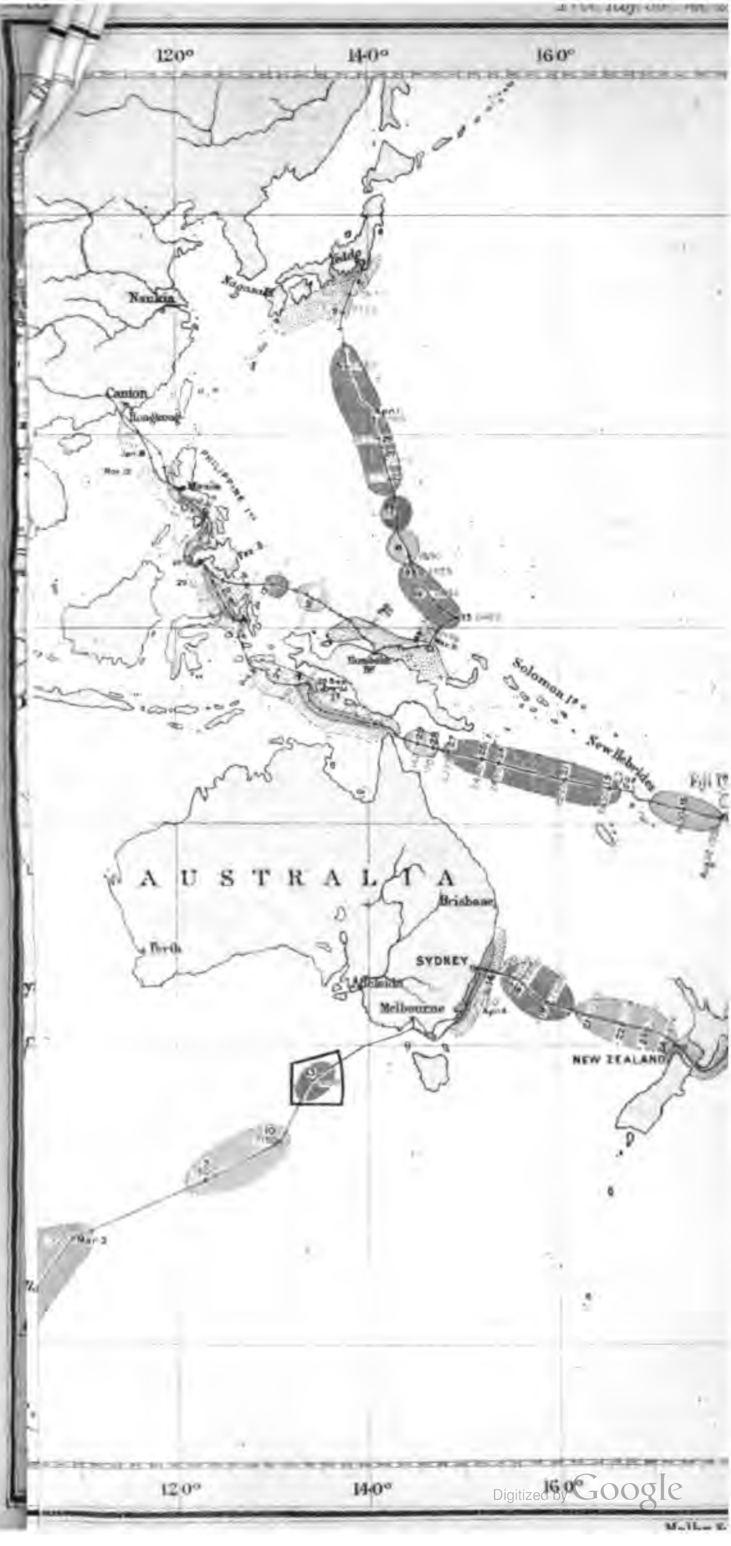
Station.	Specimen.	Number.	Depth.	Locality.	
				Lat.	Long.
			fathoms.	° ′	° ′
106.	*Maurolicus*	1	1850	1 47 N.	24 26 W.
	Sternoptyx diaphana	1			
	Melanocetus Johnsoni	1			
	Small Scopelid	1			
107.	*Bythites*	1	1500	1 22 N.	26 36 W.
	Sternoptyx	1			
	Other fish	3			
120.	Scopelid, with elongated pectoral rays	1	675	8 37 S.	34 28 W.
121.	*Nemichthys*		...	8 28 S.	34 31 W.
	Muræna, with tube-like eyes	2			
	Scopelid, small black	1			
	Other fish	3			
122.	Macrurid	1	350	9 10 S.	34 50 W
	Peristidium and other fishes				
	Balistes, Pleuronectids, *Hippocampus*.		30		
	Ostracion mathe &c.				
124.	Scopelid, with white organ on the head	1	1600	10 11 S.	35 22 W.
125.	*Synaphobranchus*	1	1200	10 46 S.	36 2 W.
126.	Scopelid, with long pectorals	2	770	10 46 S.	36 8 W.
	Small Scopelid	1			
133.	Scopelid, with white phosphorescent organ on the head	2	1900	35 40 S.	20 55 W.
	Macrurids, 3 species	5			
137.	Scopelid, small	1	2550	35 59 S.	1 26 E.

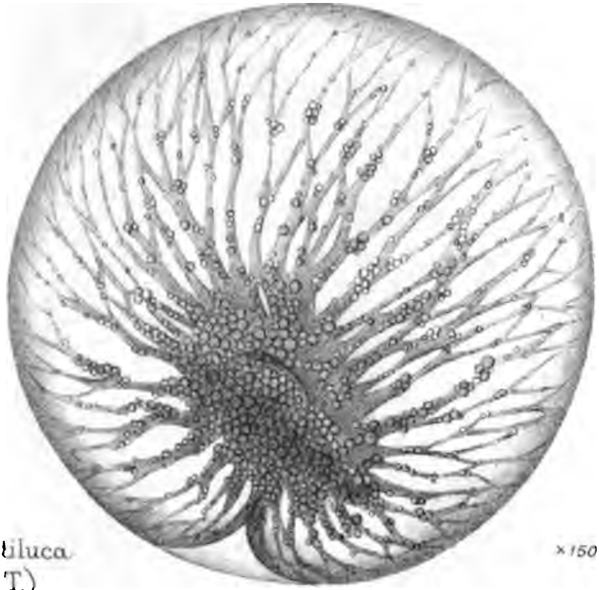
Southern and Antarctic Oceans.

Station.	Specimen.	Number.	Depth.	Lat.	Long.
145.	Large Macrurid	1	310	P. Edward Island.	
	Small Pleuronectid	1			
146.	Macrurids	14	1375	46 46 S.	45 31 E.
	Macrurid (?)	1			
	Halosaurus	4			
	Muræna	1			
	Scopelids, with mucif. canals	2			
147.	Macrurids, 1 large, 2 small	3	1600	46 16 S.	48 27 E.
152.	*Chænichthys*, deep-sea species	1	1260	60 52 S.	80 20 E.
156.	Ophidiids	2	1975	62 26 S.	95 44 E.
	Stomiatids	2			
	Leptocephalus-like fish	1			
157.	Macrurids	3	1950	53 55 S.	108 35 E.
	Scopelids	2			
158.	*Chauliodus*	1	1800	50 1 S.	123 4 E.
	Nemichthys	1			
	Macrurids	12			
	Small Sternoptychids	many.			
159.	Stomiatid, 1½ ft. in length		2150	47 25 S.	130 32 E.
	Sternoptyx diaphana				

Pacific Ocean.

Station.	Specimen.	Number.	Depth.	Locality.	
				Lat.	Long.
			fathoms.	° ′	° ′
163.	*Hippocampus*	1	120	Off Two N. C.	fold Bay, Howe.
	Dogfish	1			
	Torpedo	2			
	Raja	2			
	Pagrus	many			
	Lophioid	1			
164.	Young Macrurid	1	410	South- P. Jac	east, kson.
166.	*Trachichthys intermedius*	2	275	38 52 S.	169 20 E.
	Macrurus armatus	2			
	Platystethus abbreviatus	2			
167.	*Scorpæna Barathii*	2	150	39 32 S.	171 48 E.
	Pseudorhombus	2			
	Solea	3			
168.	Large Macrurid	1	1100	40 28 S.	177 43 E.
	Small Macrurid	3			
	Large Scopelid, 2 ft. long	1			
	Small Scopelid	1			
169.	Macrurids, 4 species	8	700	37 36 S.	179 24 E.
	Maurolicus, Scopelid	2			
170.	Small *Maurolicus*	1	520	29 55 S.	178 14 W.
	Macrurids, 3 species	several	630	29 45 S.	178 11 W.
	Scopelids	5			
	Scopelid, with long pectorals	2			
171.	Macrurid, over 2 ft.	1	600	28 33 S.	177 50 W.
	Several small species	6			
	Maurolicus	1			
	Argyropelecus	1			
173.	*Chaunax pictus*	1	315	19 10 S.	179 40 E.
	Bythites	1	310		
	Muræenid	1			
	Scopelids, 2 species	3			
	Scorpæna	2			
	Small Macrurids	3			
174.	*Maurolicus*	1	610	19 10 S.	178 10 E.
177.	*Maurolicus*	2	125	16 45 S.	168 5 E.
181.	Ophidiid, blind	1	2440	13 50 S.	151 55 E.
	Echiostoma barbatum	1			
184.	Large Ophidiid	1	1400	12 8 S.	145 10 E.
	Transparent Ophidiid	1			
	Small Ophidiid	2			
	Scopelid (*Paralepis*, c. f.)	1			
191.	Stomiatid	2	800	5 37 S.	134 4 E.
	Scopelid	1			
192.	*Peristethus*	2	129	5 42 S.	132 25 E.
	Raja	1			
	Solea	1			
	Uranoscopus	2			
	Scopelid	1			
194.	*Peristethus*		200	4 33 S.	129 58 E.
	Stomiatid		360		
	Macrurid				
	Lophioid (*Ceratias*)				
196.	*Maurolicus*		825	0 43 S.	126 59 E.

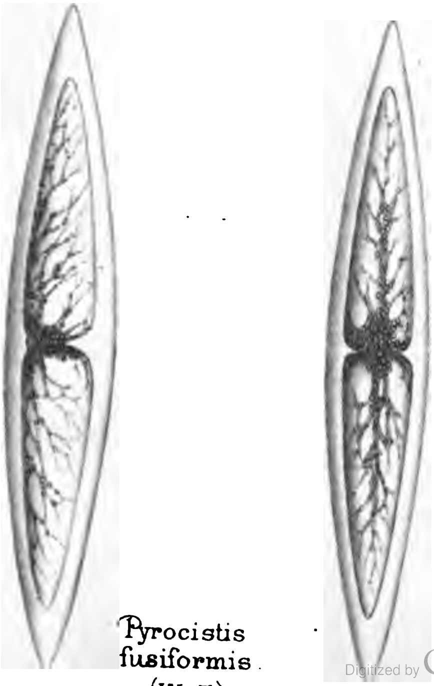

120°
140°
160°
Nankin
Nagasaki
Yeddo
Canton
Hongkong
Manila
Philippine Is.
Solomon Is.
New Hebrides
Fiji Is.
AUSTRALIA
Brisbane
Perth
Adelaide
SYDNEY
Melbourne
NEW ZEALAND
Mar 2
120°
140°
160°



nat. size
0 5 mm

×150.

Pyrocistis
pseudonoctiluca.
(Wy. T.)



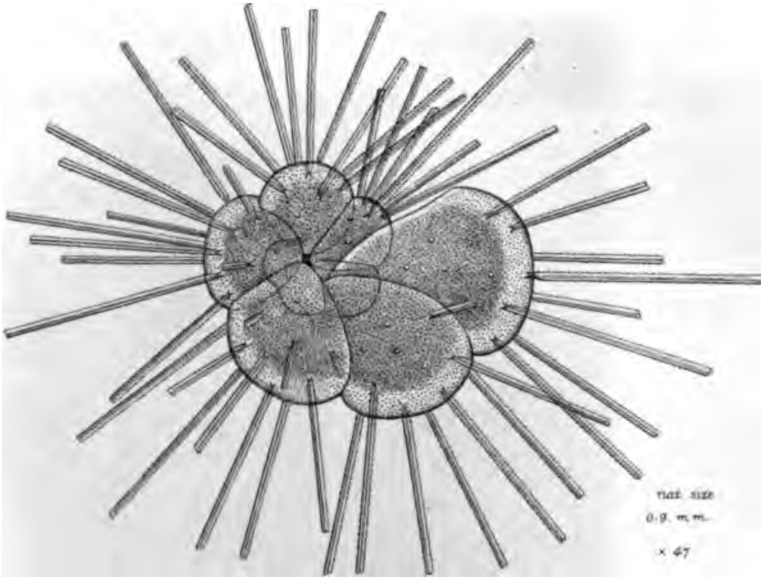
nat. size 1 mm.

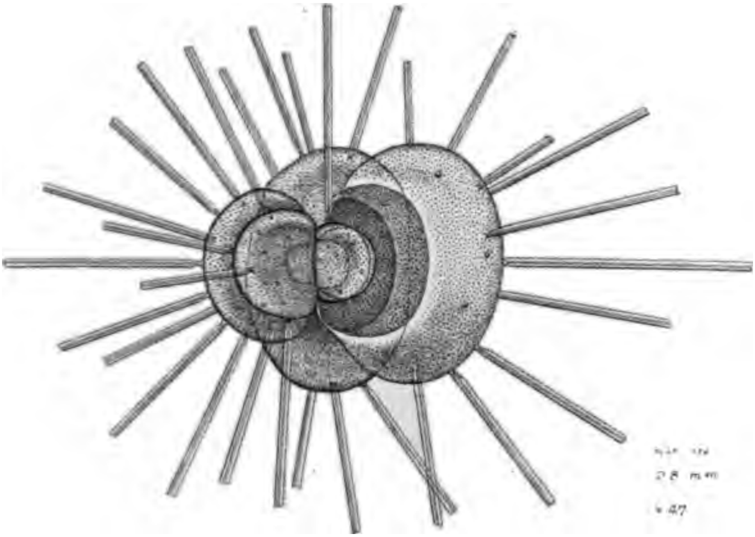
×86

Pyrocistis
fusiformis.
(Wy. T.)

G West lith.

W West & Co.

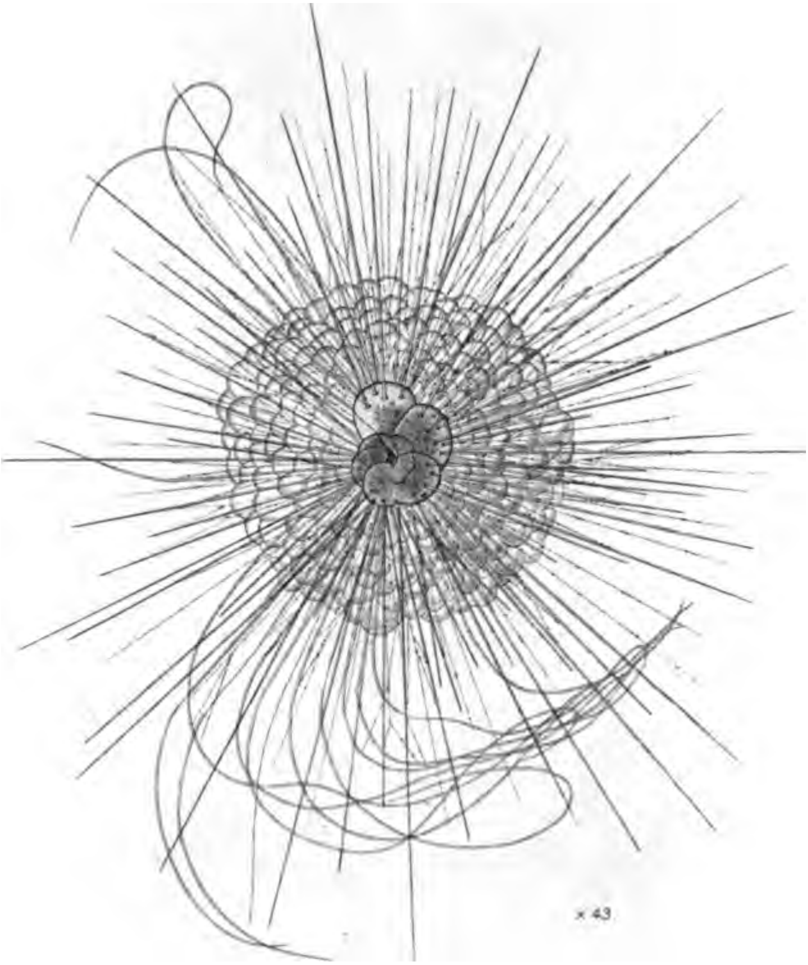




Hastigerina Murrayi (Wy. T.)

G. West lith. W. West & Co. imp.

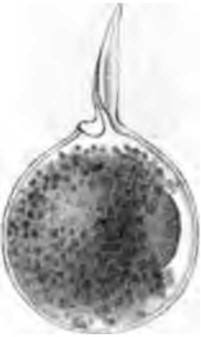
Murray. Proc. Roy. Soc. Vol. 24. Pl. 23.



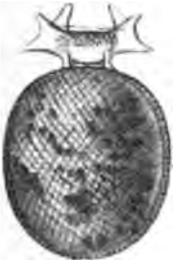
Hastigerina Murrayi (Wy. T.)

W. West lith. W. West & Co. imp.

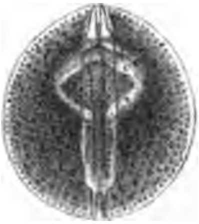
Murray. *Proc. Roy. Soc. Vol. 24. Pl. 24.*



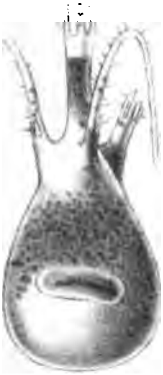
× 40



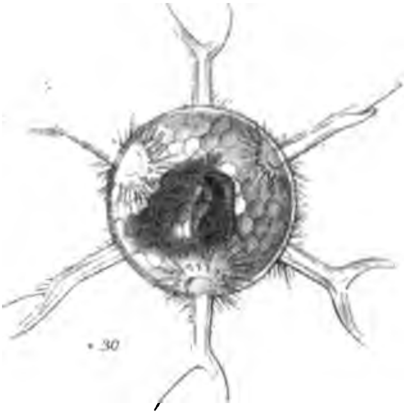
× 80



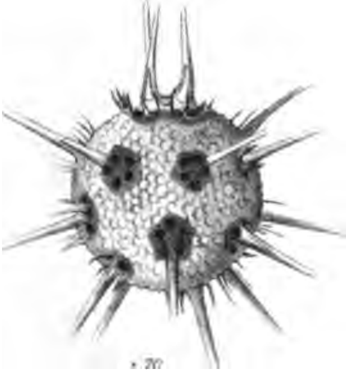
× 40



× 15



× 30



× 70

(provisionally) Challengeridæ.

G West lith W. West & Co. imp.

Pacific Ocean (*continued*).

Station.	Specimen.	Number.	Depth.	Locality.	
				Lat.	Long.
			fathoms.	° ′	° ′
198.	Ophidiid, blind	1	2150	2 55 N.	124 53 E.
	Another Ophidiid	1			
	Scopelid, with sense-organ	1			
	Other Scopelids				
200.	Small Macrurids	2	255	6 48 N.	122 25 E.
	Scopelid	1			
	Argyropelecus	1			
	Fistularia serrata	1			
205.	Ophidiids	2	1050	16 42 N.	119 22 E.
206.	Scopelid		2100	17 54 N.	117 14 E.
207.	*Trachypterus*, c. f. *spinola*	1	700	12 21 N.	122 15 E.
	Halosaurus Owenii	1			
210.	*Synaphobranchus pinnatus*	1	375	9 26 N.	123 46 E.
	Ophidiid	1			
214.	*Sternoptyx diaphana*	5	500	4 31 N.	127 7 E.
	Coccia, c. f. *ovata*	7			
	Malacosteus niger	4			
	Macrurids, 3 species	4			
	Synaphobranchus pinnatus	2			
	Scopelid (*Scopelus*)	1			
	Scopelid (*Odontostomus*)	1			
216.	*Chauliodus Sloanii*	1	2000	2 56 N.	134 11 E.
218.	*Synaphobranchus*	1	1070	2 33 N.	144 4 E.
	Ophidiid	1			
	Sternoptyx diaphana	1			
	Coccia	1			
	Small transparent fish	1			
219.	*Lophius*, *Solea*		150	1 50 S.	146 42 E.
	Peristethus (Gobiid)	4			
220.	Lophioid (*Melanocetus*)	1	1100	0 42 S.	147 22 E.
	Xenocephalus (Gadoidei)	1			
	Maurolicus	1			
223.	*Coccia*	1	2325	5 31 N.	145 13 E.
226.	*Coccia*	1	2300	14 44 N.	162 13 E.
	Small transparent fish				
230.	*Coccia*	1	2425	26 29 N.	137 57 E.
	Another Sternoptychid	1			
232.	Scopelid, new	1	345	35 10 N.	139 30 E.
	Sternoptychid	1			
	Melanocetus ...... Trawl	1			
	Shark, small	1			
	Lepidopus	1			
	Macrurids				
	Gadids				
	Synaphobranchus				
	Murænas ...... Boats	several			
	Beryx				
	Scorpæna				
	Myxene				
235.	*Sternoptyx*	1	565	34 7 N.	138 0 E.
	Stomias boa	1			
	Halosaurus Owenii	2			
	Ophidiids	2			
	Macrurids, 3 species	9			
	Platycephalus	1			
	Raja	1			
	Synaphobranchus	4			

Pacific Ocean (*continued*).

Station.	Specimen.	Number.	Depth.	Locality.	
				Lat.	Long.
			fathoms.	° ′	° ′
236.	*Coccia*		775	34 58 N.	139 30 E.
	Sternoptychids		420		
237.	Large Ophidiid	1	1875	34 37 N.	140 32 E.
	Macrurids	3			
	Synaphobranchus	8			
	Large Scopelid	1			
	Notocanthus	1			
	Sternoptychids (*Coccia*, *Maurolicus*)	2			
244.	Stomiatid		2900	35 22 N.	169 53 E.
246.	*Synaphobranchus pinnatus*	1	2050	36 10 N.	178 0 E.
	Macrurids, 2 species	6			
265.	*Coccia*	1	2900	12 42 N.	152 11 W.
271.	Large Macrurid	1	2425	0 33 S.	151 34 W.
	Scopelid, with mucif. canals	1			
	Trichiurid	1			
272.	Ophidiid, transparent	1	2600	3 48 S.	152 56 W.
276.	Scopelid	1	2350	13 28 S.	149 30 W.
281.	Scopelid	1	2385	22 21 S.	150 17 W.
285.	Stomiatid	1	2375	32 36 S.	137 43 W.
286.	Sternoptychid	1	2335	33 29 S.	133 27 W.
289.	Scopelid, with elongated pectoral rays	1	2550	39 41 S.	131 23 W.
291.	Small Sternoptychid	1	2025	39 13 S.	118 49 W.
295.	Nemichthyd, nov. gen.	1	1500	38 7 S.	94 4 W.

III. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on the true Corals dredged by H.M.S. 'Challenger' in deep water between the dates Dec. 30th, 1870, and August 31st, 1875." By H. N. Moseley, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876. Read March 16.

The following Report is to be regarded as merely preliminary, and will be followed by a full account of the corals dredged by the 'Challenger,' which can be prepared only after the termination of the present voyage.

Many specimens have been sent home for greater security, and are thus not available for comparison. Moreover, in the case of corals, it is impossible to determine, with any accuracy, specific relations without making comparisons with museum collections, which, of course, has been impossible in the present instance.

The list of corals obtained here given has been made as accurate as circumstances would permit. The amount of corals obtained by the 'Challenger' in deep water has been small, considering the very large number of dredgings which have been made. Corals have been yielded by only about forty-eight of the numerous dredgings and trawlings. Of these forty-eight hauls, twenty-five were made in 1873, thirteen in 1874, and ten in 1875. The much larger proportion of coral-yielding hauls obtained in the earlier part of the cruise is no doubt partly due to the fact that the dredge was then most frequently made use of, whereas subsequently the trawl has been almost exclusively employed, since it yields so much better general results. The majority of deep-sea corals being simple and imbedded often partly in the mud, are more readily gathered by the dredge. It is remarkable, however, that the trawl does bring up sometimes abundantly such small discoid forms as *Fungia symmetrica*; and one of the best hauls of corals obtained was made with the trawl. It was that which yielded, on Sept. 26th, 1874, between the Ké Islands and the Banda group, in 129 fathoms, two most beautiful new species of *Stephanophyllia*, a very large new species of *Deltocyathus*, a new *Platytrochus*, besides several simple *Eupsammidæ* and *Caryophylliinæ*. The following is a list of the corals obtained from depths of 50 fathoms and upwards, with a statement of all the various localities and depths at which each form has occurred.

List of Corals dredged in a depth of 50 *fathoms and upwards by H.M.S. 'Challenger,' from December* 30*th*, 1873, *to August* 31*st*, 1875, *with Depths and Localities for each Species.*

Caryophyllia clavus (Scacchi) = *C. borealis*.—2nd July, 1873: off Fayal, Azores, 50 fathoms. 10th July, 1873: lat. 37° 24′ N., long. 25° 13′ W., off the Azores, 1000 fathoms. 3rd May, 1873: lat. 38° 34′ N., long. 72° 10′ W., 1250 fathoms. 21st May, 1873: 42° 10′ N., long. 63° 39′ W., 1250 fathoms.

Caryophyllia formosa (Pourt.).—18th Feb., 1873: lat. 25° 45′ N., long. 20° 12′ W., about 300 miles E. of C. Bodajov, 1530 fathoms. 4th April, 1873: east of Bermuda, 435 fathoms.

Caryophyllia (several species).—25th March, 1873: off St. Thomas, W. Indies, 390 fathoms. August, 1873: off St. Iago, Cape-Verd Islands, 100–120 fathoms. 4th March, 1874: off Twofold Bay, N. S. Wales, 120 fathoms. 26th Sept., 1874: off the Ké Islands, in 129 fathoms.

Cœnocyathus, sp.—17th Oct., 1873: off Nightingale Island, Tristan d'Acunha, 100–150 fathoms. 26th Sept., 1874: off the Ké Islands, 126 fathoms.

Acanthocyathus, sp.—3rd August, 1874: off Kadavu, Fiji Islands, 210 fathoms.

Acanthocyathus, c. f.—25th Jan., 1875: between Panglao and Siquijor Island, 375 fathoms.

Trochocyathus coronatus (Pourt.).—25th March, 1873: north of Culebra Island, near St. Thomas, D. W. Indies, 390 fathoms.

Thecocyathus, sp.—19th Sept., 1874: off the N.E. end of Banda Island, 60 fathoms.

Deltocyathus Agassizii (Pourt.).—25th March, 1873: north of Culebra Island, near St. Thomas, D. W. I., 390 fathoms. 19th April, 1873: off Bermuda, 200 fathoms (in the sounding-machine). 29th May, 1873: off the Bermudas, 1075 fathoms. 10th July, 1873: lat. 37° 26′ N., long. 25° 14′ W., 1000 fathoms.

Deltocyathus Agassizii (Pourt.)?—23rd Sept., 1874: lat. 5° 37′ S., long. 134° 4′ E., off Dobbo, Wamma Island, Aru Islands, 800 fathoms.

Deltocyathus magnificus (sp. n).—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., S.W. of the Tionfolokker Islands, 129 fathoms.

Platytrochus rubescens (sp. n.).—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., S.W. of the Tionfolokker Islands, 129 fathoms.

Ceratotrochus diadema (sp. n.).—10th July, 1873: lat. 37° 26′ N., long. 25° 14′ W., 1000 fathoms. 9th Sept., 1873: lat. 8° 37′ S., long. 34° 28′ W., off Pernambuco, Brazil, 675 fathoms.

Ceratotrochus platypus (sp. n.).—13th June, 1874: lat. 34° 13′ S., long. 151° 38′ E., 410 fathoms, off the coast of New South Wales.

Ceratotrochus discoides (sp. n.).—9th Sept., 1873: lat. 8° 37′ S., long. 34° 28′ W., off Pernambuco, Brazil, 675 fathoms.

Ceratotrochus nobilis (sp. n.).—30th June, 1873: lat. 38° 30′ N., long. 31° 14′ W., 114 miles from Fayal, Azores, 1000 fathoms.

Turbinolidæ (undetermined).—25th March, 1873: north of Culebra Island, near St. Thomas, D. W. I., 390 fathoms. 18th Dec., 1873: lat. 35° 4′ S., long. 18° 37′ E., 150 fathoms.

Flabellum alabastrum (sp. n.).—30th June, 1873: lat. 38° 20′ N., long. 31° 14′ W., 1000 fathoms. 10th July, 1873: between St. Michael's and west end of S^ta^ Maria, Azores, 1000 fathoms.

Flabellum apertum (sp. n.).—15th Jan., 1873: lat. 37° 4′ N., long. 9° 14′ W., off the coast of Portugal, 900 fathoms. 27th Dec., 1873: off Prince-Edward Island, S. Indian Ocean, 310 fathoms.

Flabellum, sp. (same as foregoing species?).—30th Dec., 1873: lat. 46° 16′ S., long. 48° 27′ E., about 84 miles west of Hog Island, 1600 fathoms.

Flabellum variabile (Semper).—4th March, 1874: off Twofold Bay, New South Wales, Australia, 120 fathoms. 10th Sept., 1874: lat. 9° 59′ S., long. 39° 42′ E., 38 fathoms. 26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., S.W. of the Tionfolokker Islands, 129 fathoms.

Flabellum, sp.—4th March, 1874: off Twofold Bay, New South Wales, Australia, 120 fathoms.

Flabellum, sp.—12th May, 1875: lat. 35° 10′ N., long. 139° 30′ E., off Inosima, Kamakura Bay, Japan, 345 fathoms. 4th June, 1875:

lat. 34° 7′ N., long. 138° 0′ E., about 35 miles S.S.W. of Omae Saki Lighthouse, Japan, 565 fathoms.

Flabellum, sp. (variety of the foregoing species?).—1st March, 1875: lat. 2° 33′ S., long. 144° 4′ E., about 40 miles north of Rossig Island, Schouten Island, 1070 fathoms.

Flabellum angulare, sp. n.—21st May, 1873: lat. 42° 10′ N., long. 63° 39′ W., 1250 fathoms.

Cyathohelia axillaris (M.-Edw. & H.).—13th Oct., 1874: lat. 0° 45′ S., long. 126° 59′ E., 825 fathoms.

Lophohelia Carolina (Pourt.).—15th March, 1873: off Sombrero Island, D. W. I., 460 fathoms.

Lophohelia prolifera (M.-Edw. & H.).—25th March, 1873: north of Culebra Island, near St. Thomas, D. W. I., 390 fathoms.

Lophohelia, sp.—17th October, 1873: off Nightingale Island, Tristan d'Acunha, 100–150 fathoms.

Lophohelia, sp.—29th Sept., 1874: off Banda Island, 360 fathoms.

Lophohelia, sp.—25th Jan., 1875: lat. 9° 26′ N., long. 123° 46′ E., between Panglao and Siquijor Island, Philippines, 375 fathoms.

Lophohelia, sp.—28th August, 1873: off St. Paul's Rocks, Atlantic, 100 fathoms.

Amphihelia, sp.—18th Oct., 1873: between Nightingale Island and Tristan d'Acunha, 1000 fathoms. 26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., south-west of the Tionfolokker Islands, 129 fathoms.

Genus of *Oculinidæ*, sp.—18th August, 1874: off Api, New Hebrides, 60 fathoms.

Madracis Hellana (Valenciennes in M.-Edw. & H.).—4th April, 1873: east of Bermuda, 435 fathoms.

Genus of *Astræaceæ*, sp.—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., south-west of the Tionfolokker Islands, 126 fathoms.

Cladocora arbuscula (M.-Edw. & H.).—4th April, 1873: east of Bermuda, 435 fathoms.

Stylaster Duchassaingii (Pourt.), c. f.—10th Sept., 1873: lat. 9° 10′ S., long. 34° 39′ W., off Point Calvo, Brazil, 400 fathoms.

Stylaster complanatus (Pourt.).—15th March, 1873: close to Sombrero Island, D. W. I., 460 fathoms.

Stylaster (c. f.), sp.—10th Feb., 1875: lat. 4° 31′ N., long. 127° 7′ E., off the Meangis Islands, 500 fathoms.

Stylaster, sp.—Same locality.

Genus of *Stylasteraceæ*.—4th July, 1874: lat. 29° 55′ S., long. 173° 14′ W., off Raoul Island, 520 fathoms.

Cryptohelia, sp. (*C. pudica*, c. f.).—18th Feb., 1873: lat. 25° 45′ N., long. 20° 12′ W., 1530 fathoms. 25th March, 1873: off Sombrero, D. W. I., 390 fathoms. 15th July, 1874: lat. 28° 33′ S., long. 177° 50′ W., about 45 miles north of Raoul Island, Kermadec Island, 600 fathoms. 5th June, 1875: lat. 34° 58′ N., long. 139° 30′ E., between Vries Island, Oosima, and Cape Sagami, Japan, 775 fathoms.

Balanophyllia, sp.—26th Oct., 1874: lat. 7° 32′ N., long. 121° 48′ E., Basilan Str., Philippines, 102 fathoms.

Balanophyllia, sp.—10th Sept., 1873: lat. 9° 10′ S., long. 34° 39′ W., off Port Calvo, Brazil, 400 fathoms.

Genus of simple *Eupsammidæ*, 2 sp.—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., south-west of Tionfolokker Islands, 129 fathoms.

Dendrophyllia ramea (Blainv.).—August, 1873: off St. Iago, Cape-Verd Islands, 100–120 fathoms.

Stephanophyllia complicata, sp. n. (*S. florealis*, Quenstedt, c. f.).—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., south-west of the Tionfolokker Islands, 129 fathoms.

Stephanophyllia formosissima (sp. n.).—26th Sept., 1874: lat. 5° 42′ S., long. 132° 25′ E., south-west of the Tionfolokker Islands, 129 fathoms. 20th Jan., 1875: off Cebu, Philippine Islands, with *Euplectella aspergillum*, 95 fathoms.

Fungia symmetrica (Pourt.).—25th March, 1873: north of Culebra Island, near St. Thomas, D. W. I., 390 fathoms. 22nd April, 1873: south-west bank off Bermudas, 30 fathoms. 29th May, 1873: south-west of Bermudas, 1075 fathoms. 30th June, 1873: lat. 38° 30′ N., long. 31° 14′ W., 114 miles from Fayal, Azores, 1000 fathoms. 10th July, 1873: lat. 37° 26′ N., long. 25° 14′ W., 1000 fathoms. 11th Oct., 1873: lat. 35° 41′ S., long. 20° 55′ E., about 400 miles west of Inaccessible Island, Tristan d'Acunha, 1900 fathoms. 25th August, 1874: lat. 13° 50′ S., long. 155° 55′ E., south-west of the Louisiade Archipelago, 2440 fathoms. 3rd March, 1874: lat. 53° 55′ S., long. 108° 35′ E., 1950 fathoms. 29th Sept., 1874: off north end of Banda Island, 360 fathoms. 3rd Oct. 1874: lat. 4° 21′ S., long. 129° 7′ E., between Banda and Amboyna, Moluccas, 1425 fathoms. 13th Oct., 1874: lat. 0° 45′ S., long. 126° 59′ E., 825 fathoms. 1st March, 1875: lat. 2° 33′ S., long. 144° 4′ E., about 40 miles north of Rossig Island, Schouten Island, 1070 fathoms. 21st March, 1875: lat. 7° 45′ N., long. 144° 20′ E., 1850 fathoms. 23rd June, 1875: lat. 35° 41′ N., long. 157° 42′ E., North-west Pacific, 2300 fathoms. 28th June, 1875: lat. 32° 22′ N., long. 169° 53′ E., 2900 fathoms.

Pliobothrus, sp. n. (Pourt.).—15th March, 1873: close to Sombrero Island, D. W. I., 460 fathoms.

Dead Fragments drifted from Shallow-shore Regions.

Tubipora, sp.
Madrepora nasuta, c.f. } 29th Sept., 1874 : off Banda Island, 200 fathoms.

List of Corals dredged from less than 50 fathoms, but of especial interest.

Madracis asperula (M.-Edw. & H.).—22nd April, 1873 : south-west bank off Bermudas, 30 fathoms ; St. Vincent, Cape-Verd Islands, shallow water ; Fernando de Noronha, shallow water.

Flabellum variabile (= *F. Stokesii* = *F. Oweni* = *F. aculeatum* = *F. spinosum*, Semper, 'Generationswechsel bei Steinkorallen').—12th Sept. 1874 : lat. 8° 56′ S., long. 136° 5′ E., Arafura Sea, 49 fathoms.

With this species :—*Rhodopsammia socialis* (Semper), *Rhodopsammia parallela* (Semper), and a genus of *Astræaceæ*.

Heliastræa cavernosa (M.-Edw. & H.).—10th Sept., 1873 : off Barra Grande, Brazil, 30 fathoms.

Fungia symmetrica.—22nd April, 1873 : south-west bank off Bermudas, 30 fathoms.

Notes on the Corals enumerated in the foregoing List.

Caryophyllia clavus (Scacchi).

Professor Martin Duncan (Ann. and Mag. Nat. Hist. 1870, vol. v. 4th ser. p. 289) has remarked on the wide variation displayed by this species, and, after an examination of a long series of specimens, has concluded that *C. clavus*, *C. Smithii*, *C. cyathus*, and *C. borealis* are to be regarded as varieties of one and the same species, for which the name *C. clavus* is adopted by him in his final description of the corals dredged by H.M.S. 'Porcupine.' Many varieties of this form have been obtained by the 'Challenger;' but the series obtained in each separate locality have been remarkably uniform, showing a similarity of variation produced in the species by the action of certain external conditions. This fact has been found to hold good, not only in the case of *Caryophyllia clavus* but also in that of *Deltocyathus Agassizii* and *Fungia symmetrica*, as will be subsequently described. As instances may be cited the two following hauls of *C. clavus* :—On July 10, 1873, in the neighbourhood of the Azores, in lat. 37° 24′ N., long. 25° 13′ W., about thirty specimens of the coral were obtained from 1000 fathoms. Many of them were in the fresh condition with the soft parts uninjured. The corals were all sharply conical, with narrow, pointed, unattached bases, and all uniformly curved. They were from a bottom of fine mud, where only very small particles are present for the attachment of the young coral. On dredging off the island of Fayal in the Azores in a depth of 50 fathoms, another series of *C. clavus* was obtained. Here the bottom was composed of irregular masses made up of a coarse volcanic sand cemented by *Serpula*-tubes. The adult *Caryophyllias* were attached to these masses by broad bases, and were all remarkably small, no doubt from the unfavourable condition in which they existed on a volcanic bottom.

The largest of the series of 30 specimens of the curved variety of *C. clavus* measured 2 centims. in height. The soft parts of the animals were transparent and almost colourless.

Acanthocyathus, sp.

Obtained off Kadavu, Fiji Islands, August 3, 1874, in 210 fathoms. The specimen appears to be closely allied to *A. Grayi* as described by Milne-Edwards[*]. It differs in being attached, not free; but the pedicle of attachment is very fine. *A. Grayi* has its lateral costæ provided with three or four spines, very strong, horizontal, and compact. In the present specimen the spines are developed only on one of the lateral costæ, and indicated by indentations on the other. The calicle is oval in horizontal section, as in *A. Grayi*. Three species of *Acanthocyathus* have been described, viz. *A. Grayi*, recent, locality unknown; *A. Hastingsæ*, of Miocene age, from Malta (M.-Edw. & H., *l. c.*); and *A. spiniger*, recent, from Japan, lately described by Saville Kent[†].

Trochocyathus coronatus (Pourt.).

The corallum is white. It is free, but with a small scar of adherence. It is circular in horizontal section, with a broad flat base, with the plane of which the walls of the calicle, sloping outwards, make an angle of about 60°. At the junction of the wall of the calicle with the base, the base is continued horizontally outwards into twelve stout spines, irregularly beset with small pointed tubercles. The spines correspond in position with the primary and secondary costæ. There are six systems of septa, and four cycles, with a partial fifth cycle in large specimens. The septa of the four cycles are complete. All the septa are exsert. The primary, secondary, and tertiary septa bear pali, those of the tertiary septa being the most developed. The columella is large and composed of a tubercular mass of contorted papillæ. The largest specimen measures 27 millims. in diameter of the calicle, and 32 millims. in extreme diameter between the tips of the exsert septa. Its extreme height is 20 millims.

Five specimens of this coral were obtained off St. Thomas, D. W. I., in 390 fathoms. One of the specimens, being very young, was seen to be identical with the young and imperfect specimen figured and described by Count Pourtales as *T. coronatus*[‡]. The young form differs very much from the adult, the spines being scarcely at all developed. In its tendency to develop a fifth cycle of septa this species conforms with the *Trochocyathi armés* of MM. Edwards and Haime, a large number of these having five cycles. The present species is, with the exception of *T. philippinensis* (Semper, *l. c.* p. 21, tab. xx. fig. 16), the only known recent one. The fossil species range from the Lias to the more recent Tertiary beds. They are most abundant in Miocene deposits.

---

[*] MM. Milne-Edwards et J. Haime, 'Hist. Nat. des Coralliaires,' t. ii. p. 22.

[†] W. Saville Kent, "On new Madrepores," Proc. Zool. Soc. 1871, p. 275.

[‡] Pourtales, *l. c.* p. 15.

Thecocyathus, sp.

Only a single specimen of this genus has been dredged off Banda Island in 60 fathoms. The specimen is young, with roots only just commencing to be formed.

Deltocyathus Agassizii.

This coral has been dredged on five occasions. On one occasion thirteen specimens, all dead, were obtained. On another, July 10, 1873, lat. 37° 26′ N., long. 25° 14′ W., fifty specimens were procured at one haul, most of them with the soft parts *in situ*. An examination of this latter fine series gives the following results. Although the series obtained near St. Thomas, D. W. I., appeared to bear out Pourtales's assertion that the young coralla of this species are cup-shaped, and that they gradually become more saucer-shaped as age advances, such is not the case in the long series of fifty specimens. In this nearly all the larger specimens have the calicle deeply cup-shaped, whilst the younger ones are flatter, and some of the very small ones (2·5 millims. in diameter) absolutely flat. Some of the specimens are 14 millims. in diameter, a shade larger than Pourtales's largest specimen. The series presents points of well-marked variation from the West-Indian specimens. The coralla are all characterized by having their primary and secondary septa, as well as their pali, extremely exsert; but the pali never project so high as the septa to which they are soldered at their bases, as they do in Pourtales's specimens and in the specimens dredged by the 'Challenger' in the West Indies. No tendency towards the horned variety described by Pourtales is to be seen in the present series. The coralla, in being more cup-like than specimens hitherto obtained, approach the fossil *D. italicus*, as figured in Bronn's 'Klassen und Ordnungen des Thierreichs;' but the difference in the nature of the costæ, relied upon as distinctive between the two species by Pourtales, is as well marked here as in all other specimens obtained by us. Professor Martin Duncan considers *D. Agassizii* to be not specifically distinct from *D. italicus*. A direct comparison of the long series of specimens of the recent species obtained by us with the fossil form will no doubt determine this point.

Deltocyathus Agassizii (horned variety of Pourtales).

M. de Pourtales, in his description of *Deltocyathus Agassizii*, gives an account of varieties of that species in which the primary costæ are large and prolonged beyond the margin of the calicle, forming a star. One mutilated specimen is figured by this author, in which the primary costæ are prolonged into horn-like appendages as long as one fourth the diameter of the calicle [*]. In sounding off Bermuda, on April 17, 1873, in about 200 fathoms, a finely preserved specimen of this variety was obtained, in which the horn-like appendages are developed to a remarkable degree. The diameter of the calicle is 9 millims.; the length of the horns or spines is 3·5 millims., or more than one third the diameter of the calicle. The horns have no accessory prong as in Pourtales's specimen; they are slender, rounded, and taper to a fine point. A somewhat smaller horn is developed in relation with one of the secondary costæ, although the remaining secondary costæ show no tendency to elongation. The horned or stellate variety of *D. Agassizii* appeared to Pourtales, at first, to present good specific characters; but the examination of intermediate forms showed that it was not specifically distinct. None of these intermediate forms have been obtained by us, the single specimen of the extreme condition of the variety standing quite isolated. The specimen, which is in most excellent preservation, shows further points of interest. Thus the pali, as a whole, project more prominently above the general elevation of the septa than is the case in the normal specimens; and the V or delta formed by the junction of the secondary with the tertiary pali is prominent and conspicuous; so that in this respect the coral approaches the fossil species *D. italicus*, as figured by Bronn [†], more closely than do the normal species; and there are, further, present around the columella, or, rather, to be considered as forming part of it, six small rounded projections covered with minute spines placed regularly, one opposite each of the secondary septa, as appears to be the case in the fossil form. In other respects, however, the specimen shows the same differences from *D. italicus* as are presented by the normal specimens and as are described by Pourtales, viz. the costæ are covered with fine sharp granulations, not formed of large grains, and the columella, or rather its central portion, shows no traces of a threefold arrangement. The corallum is an almost flat disk, much flatter than any other specimens of *D. Agassizii* obtained by us.

During a visit which I paid to Boston in the spring of 1873, Count Pourtales informed me that he had obtained a series of specimens of the stellate variety of *D. Agassizii* from Barbadoes, where all the specimens of this coral seemed to assume this remarkable form.

Deltocyathus magnificus, sp. n.

This name has been given to a gigantic example of this genus, of which two living specimens were obtained from 126 fathoms between the Ké Islands and the Banda group.

The corallum is quite flattened and discoid. The inferior surface is slightly concave, the margin of the calicle being somewhat tumid. The tissue composing the corallum is dense, and of a slight reddish-yellow tint—not white as in *D. Agassizii*. In the structure of the columella this species differs more strongly than *D. Agassizii* from *D. italicus*, the columella being very diffuse and finely trabecular, whilst there is no trace of the rows of tubercles on the costæ. A fifth cycle of septa is fully developed, whereas the other two species of the genus have only four cycles. All the septa bear pali disposed in four crowns, the quaternary pali being largest. The diameter of the corallum is 3 centims. The disk of the living animal was of a light ochre-yellow colour, somewhat reddened towards the margin of the calicle. The tentacles were white.

---

[*] Pourtales, *l. c.* pl. 5. figs. 9 & 10.

[†] Bronn, Kl. und Ordn. des Thierreichs, 2te Bd. t. iv. fig. 10.

Platytrochus rubescens, sp. n.

The corallum is compressed and wedge-shaped, without trace of adherence, and provided with lateral aliform expansions derived from the lateral costæ. It has six systems of septa and four cycles. The septa are exsert with rounded superior borders. The columella is elongate and fascicular. The corallum is of a pale reddish colour. In outward aspects this coral resembles the genus *Endopachys* *, but shows no trace of perforate structure. It appears also related to the genus *Sphenotrochus* †, in which, however, there are only three cycles of septa, and the septa are not exsert. *Sphenotrochus crispus* has the lateral costæ more developed than those of the faces. It is placed provisionally in the genus *Platytrochus*, which, however, has in the species known only three cycles of septa. The *Platytrochi* have broad, lateral costæ. *Pl. Stokesii* was placed by Lonsdale in his genus *Endopachys*. Several living specimens and two dead ones of *Pl. rubescens* were obtained from 129 fathoms off the Kó Islands.

Ceratotrochus diadema, sp. n.

The corallum is white; it is shallow and saucer-shaped; it has a short, rudimentary pedicle, with small scar of adherence. The primary and secondary costæ are prominent and serrate. There are six systems of septa and five cycles. The whole of the septa are exsert, the primary and secondary extremely so, projecting 1 centim. above the margin of the calicle. The quinary septa unite with the quaternary, the quaternary with the tertiary, and the tertiary with the secondary. The primary septa remain free throughout their whole course to the columella. The columella is large and oval, and composed of contorted fascicular matter.

The extreme diameter of the corallum between the tips of the exsert septa is 5·75 centims., the extreme height 2·15 centims.

A young specimen of this coral, with the soft parts *in situ*, was dredged on 10th July, 1873, in lat. 37° 26′ N., long. 25° 14′ W., from 1000 fathoms; and a single adult specimen was obtained from off Pernambuco, Brazil, in 675 fathoms. It was without soft parts, but only recently dead.

---

* MM. Edwards and Haime, *l.c.* t. iii. p. 97.

† Ibid. t. ii. p. 65.

Ceratotrochus platypus, sp. n.

The corallum is shallow and circular, with a wide horizontal base, from which the low calicular wall rises abruptly and almost vertically. A rudimentary peduncle is present attached to a small spiral shell, which, together with the peduncle, becomes buried and obliterated in fully grown specimens. Primary and secondary costæ are slightly marked; they are simple, without teeth. There are six systems of septa and five cycles. The quinary septa are incomplete. The septa are not fused with one another. The primary and secondary septa are extremely exsert. Well-marked pali are present on three of the septa of the larger specimen; otherwise pali are absent. The columella is rudimentary.

Extreme diameters of two specimens 4·6 centims. and 3·5 centims.; extreme heights of the same 2·2 centims. and 1·9 centim. They were procured together in lat. 34° 13′ S., long. 151° 38′ E., in 410 fathoms. Both specimens had evidently been dead a long time.

Ceratotrochus discoides, sp. n.

This species resembles *C. diadema*, but is evidently specifically distinct. The corallum is of the same shallow saucer-shape. The septa are less exsert than in *C. diadema*, and there are only four cycles of septa, the fourth cycle being imperfect. The secondary and tertiary septa are not fused to one another. The columella is little developed, and made up only of the fusion of the swollen inner ends of the septa; it is excavated in its centre. A scar of attachment is present, and similar to that in *C. diadema*. The costæ are serrate. The diameter of the corallum is 2·1 centims. The specimen is evidently adult. Only one specimen has been obtained, from 675 fathoms, lat. 8° 37′ S., long. 34° 28′ W., off Pernambuco.

Ceratotrochus nobilis, sp. n.

This species differs from the three preceding in being deep and cup-shaped, the base being rounded, conical in form, and not flattened. A scar of attachment is present. The costæ are beset with short teeth. The septa are exsert with rounded summits. There is no trace of pali. Only one specimen has been obtained, 114 miles from Fayal, Azores, in 1000 fathoms.

Note on the four Species of Ceratotrochus *above described.*

The four species of corals above described are evidently very closely related to one another. In all the septa are remarkably exsert, in *C. platypus* extraordinarily so. All show traces of original attachment, and are subpedicellate. In all but *C. platypus* the costæ are armed with short spines or teeth. In its general form *C. platypus* recalls *Trochocyathus coronatus*, and it is remarkable that it shows a tendency to develop pali. The corals have been placed provisionally in the genus *Ceratotrochus.* New genera will possibly have to be formed for *C. platypus* and *C. diadema.*

Flabellum alabastrum, sp. n.

The corallum is of a beautiful light pink colour, and is very thin and fragile. It is wedge-shaped, with an attenuated pedicle. The lateral costæ are sharp, with slightly prominent irregular edges; they make an angle with one another of from 120° to 140°. The external surface of the corallum is covered with a glistening epitheca. The primary and secondary costæ of the faces are almost as well marked as the lateral costæ, and appear as irregularly dentate ridges, separated by slight depressions. The calicle is compressed from side to side in its centre. Its upper margin is curved, describing about one third of a circle, and is deeply indented, the primary and secondary costæ being prolonged into prominent pointed processes. There are six systems of septa disposed in five cycles. The primary and secondary septa are, approximately, equal; the tertiary, quaternary, and quinary successively narrower. The quaternary septa join the tertiary at a short distance before reaching the columella. The septa of the fifth cycle are incomplete. Three perfect specimens obtained had about the same dimensions. Extreme height of the calicle 5 centims., longest diameter 6·5 centims., shortest diameter 3 centims. The complicated, sharply-toothed margin of the calicle forms the most striking feature about this *Flabellum.* Its extreme fragility is remarkable in so large a species. It appears to belong to the division of the genus *Flabella subpedicellata* of MM. Edwards and Haime, and to the subdivision of these characterized by having the costæ prominent and ridge-like on the faces, as well as on the lateral margins. These corals, however, have the fifth cycle of septa complete. Two of the specimens obtained were alive, and expanded themselves when placed in sea-water, notwithstanding the depth from which they came. The inner margin of the disk around the elongate mouth presents a regular series of dentations corresponding with the septa, and is of a dark madder colour; the remainder of the disk is of a pale pink. The tentacles take origin directly from the septa; they are of an elongate conical form; those of the primary and secondary septa are equal in size and placed nearest the mouth and at an equal distance from it, together with the tertiary tentacles, which are somewhat shorter, but are placed in the same row with them. The tentacles of the fourth and fifth cycles are successively smaller, and placed at successively longer distances from the mouth. Placed on either side of each tentacle of the fifth cycle, and again somewhat nearer to the margin of the calicle, are a pair of very small tentacles which have no septa developed in correspondence with them. The number of tentacles is thus ninety-six. The tentacles are light red in colour. Between their bases are stripes of yellowish red and pale grey. This coral was dredged twice in the neighbourhood of the Azores from 1000 fathoms; five specimens, three living and two dead, were obtained.

Flabellum apertum, sp. n.

The corallum is much compressed at the base, where it forms a short pedicle, which is attached in one specimen to a minute rolled particle of basalt. Above the pedicle the walls of the corallum curve outwards, so as to form a widely open, almost cup-shaped calicle. The summits of the calicle at the termination of the long axis are a little lower than those at the termination of the short axis. The wall of the calicle presents twelve prominent costal ridges separated by intervening rounded excavations. The primary ridges are more marked than the secondary, and the lateral costæ slightly more prominent than the others, and continued almost to the apex of the pedicle. The surface of the wall and costal ridges is smooth, and covered with a glistening epitheca. The margin of the calicle is deeply and irregularly dentate, with sharply angular prominences corresponding to the primary and secondary costæ. The septal arrangement is remarkable for its simplicity and symmetry as occurring in a *Flabellum*. There are four cycles of septa in six systems, and these are present in every specimen obtained without any irregularity, the systems being all of the same breadth. The columella is little developed, and composed of scanty outgrowths from the inner ends of the septa.

Extreme height of the largest specimen 2 centims.; longer axis of the calicle 3·4 centims., shorter axis 2·3 centims.

The mean proportion of the axes of the series is about 100 to 137. This *Flabellum* has a wide range, having been obtained by us off the coast of Portugal, and also off Prince-Edward Island in the South Indian Ocean, in 900 and 310 fathoms respectively.

Flabellum angulare, sp. n.

The corallum is thin and fragile and of a pearly white, covered externally with a glistening pellicular epitheca. The calicle is vase-shaped, widely open, the diverging walls making with one another an angle of about 110°. A short cylindrical pedicle is present. The mouth of the calicle is even and pentagonal in outline; from each angle of the pentagon a stout costal ridge, very slightly dentate, runs down to the pedicle. Between these costæ the wall of the calicle presents five faces, almost flat, but with slightly marked secondary costæ. The septa are in five systems and four cycles; they consist of extremely fragile laminæ covered with granules on their faces. The septa are complete, except the quaternary, which reach to a very short distance only from the calicular margin. The columella is well developed and trabecular, formed of outgrowths of the inner ends of the septa; it is deeply placed in the calicle, the free vertical margins of the primary and secondary septa extending above it for a considerable height.

Extreme breadth of the calicle 2·45 centims., extreme height 1·1 centim.

The coral was obtained in lat. 42° 10′ N., long. 63° 39′ W., from 1250 fathoms off the coast of Nova Scotia. The single specimen as yet obtained is evidently abnormal in its arrangement in fives. This arrangement in fives is perfect. There are exactly 40 septa—10 primary and secondary in dimensions, 10 tertiary, and 20 quaternary.

Cyathohelia axillaris.

A single specimen of this species, broken but quite fresh, was obtained from 825 fathoms, in lat. 0° 45′ S., long. 126° 59′ E. This very peculiar form was hitherto known only from Japan. It is quite a new genus amongst deep-sea corals.

Cryptohelia pudica (?).

Of *Cryptohelia Piercii*, Pourtales only obtained very small and badly developed specimens. A large series of specimens of this genus has been dredged by us. They show great variation; and, some being evidently identical with *C. Piercii* (Pourt.), others seem to show that this species is merely a dwarfed form of *Cryptohelia pudica* of Milne-Edwards and Haime, from which our best-developed specimens are apparently indistinguishable. Further, as has already been pointed out by Pourtales, the genus *Endohelia* of Milne-Edwards and Haime[*] appears indistinguishable from the genus *Cryptohelia*. We dredged specimens of an undoubted *Cryptohelia*, apparently of the same species as our other deep-sea specimens, off Japan in 775 fathoms, in the living condition. The genus *Cryptohelia* appears to be a characteristic deep-sea one, with a remarkably wide range, as with most other deep-sea forms. We have obtained it in the neighbourhood of the Canary Islands and off the Danish West Indies in the Atlantic, whilst Pourtales obtained it from off Bahia, off Bahia Honda, and off Sombrero, D. W. I. We further obtained it near the Kermadec Islands in the South-west Pacific and off the coast of Japan. M.-Edwards's original specimen was from New Guinea, and therefore probably not from deep water. The coral was, however, not met with by the 'Porcupine' in the Northern Atlantic.

Dendrophyllia ramea.

Occurs with *Corallium rubrum* at the Cape-Verd Islands in from 100 to 120 fathoms just as it occurs with *Corallium* in the Mediterranean. It occurs also in 100 fathoms off Setubal in Portugal, but there without *Corallium*[†].

---

[*] M.-Edw. & H. *l. c.* t. ii. p. 128.

[†] Saville Kent, Ann. & Mag. Nat. Hist. 1870, vi. p. 461.

Stephanophyllia complicata and *S. formosissima.*

Two species of corals, procured from 126 fathoms in the neighbourhood of the Ké Islands, have been referred to the genus *Stephanophyllia.* Both species are discoid, and have their wall extremely perforate; in fact composed merely of finely trabecular tissue. Two genera of discoid corals, *Micrabacia* and *Stephanophyllia*, are given by M.-Edwards and Haime*, which present this peculiarity of having their wall covered with minute perforations, so as to be sieve-like in appearance. The genus *Micrabacia* is placed amongst the imperforate corals; whilst *Stephanophyllia* is considered one of the Eupsammidæ. The differences between the two genera seem difficult to define. Both are remarkable for having the costæ corresponding in position to the interspaces between the septa, and not to the septa themselves. The present species are placed in the genus *Stephanophyllia,* because in one species all the septa, excepting the primary, fuse together before reaching the columella; whilst in the second species a peculiar extreme fusion and contortion of the septa takes place with the advancing age of the coral, which *renders it very like Stephanophyllia florealis* figured by Quenstedt †. The alternation of the costæ with the septa, the presence of five cycles of septa, and perforation of the base here occurring are characters common to both genera, *Micrabacia* and *Stephanophyllia.* The two species here described are placed provisionally in the genus *Stephanophyllia*; a new genus may have to be formed for them. They seem to have little or no affinity to the Eupsammidæ.

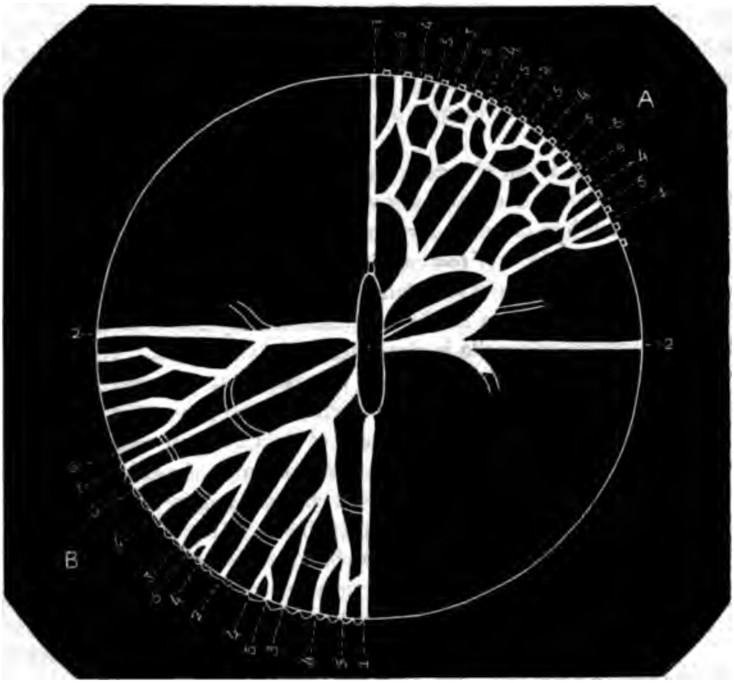
Stephanophyllia complicata, sp. n.

The corallum is circular, free, and without trace of adherence: it has the form of a biconvex lens, the base being very slightly curved, and the upper surface greatly so. The under surface, or wall, is perforated by rows of oblong holes arranged in regular series along the interspaces between the costæ. The costæ are fine ridges covered with small swellings and granules, which radiate out with great regularity from the centre of the basal disk; they commence in the centre from six very short roots of origin, which immediately bifurcate, thus becoming twelve. The bifurcation of each of the costal ridges proceeds at successive distances from the centre, until at the margin of the adult coral there are 96 costæ present, 16 in each system. The costæ at the margin of the calicle are slightly grooved, showing a tendency to divide again. The perforations between the costæ form about 22 concentrically arranged rows. The coral is very convex above the septal meshwork, rising in an even curve which culminates at the columella. There is scarcely any central fossa. There are six systems of septa and five cycles. The primary septa are thin straight lamellæ with untoothed margins, which proceed directly from the periphery to the base of the columella. At about half their length from the periphery to the centre of the calicle is a notch followed by a sudden rise, which forms thus a distinct palus, from the summit of which the line of the inferior margin of the septum slopes sharply down to the base of the columella. The secondary septa are also straight thin laminæ; they can be traced in the adult coral no further than for about one third the distance from the periphery to the columella, since they are here covered by the tertiary septa, which, bending over the secondary septa at this point, bring together their upper margins, and, fusing with one another, form stout laminæ, which run in a radial direction to join the columella, and are the stoutest and most conspicuous septa in the coral. From their point of junction with the secondary septa, the tertiary septa curve outwards towards the primary septa on either side in each system; and each of them being joined on its side next the primary septa by a curved quaternary septum, curved lines of septal matter are formed which are fused by short, transverse, synapticular laminæ to the primary septa, at points very near the centres of the

---

* M.-Edw. & H. *l. c.* t. iii. pp. 39 & 108.

† Petrefactenkunde, Taf. lxxvi. no. 12, p. 789; Jura, p. 787.



Shows the arrangement of the septa in the adult and young *Stephanophyllia complicata.* The specimens were taken September 26, 1874, in 129 fathoms off the Ké Islands.

A. Adult, diam. 1·7 centim. B. Young, diam. 6 millims.

lengths of each of these. Thus is brought about the peculiar arrangement which forms the most striking feature presented by the adult coral, and which consists *in the presence around the elongate columella of six symmetrically arranged oval hollow spaces, each of which is enclosed by a loop-like lamina, as it were, of hard tissue, and bisected longitudinally by the inner end of the palus of the corresponding primary septum* (see accompanying diagram, p. 559).

In their further course, the tertiary septa are bent from side to side in a most remarkable manner, and fusing at successive distances outwards with the shorter quaternary and still shorter quinary septa, which are likewise extremely undulate in their course, a series of chambers is formed, which chambers are closed at their peripheral ends by processes of synapticular matter. The chambers are arranged symmetrically in each system on either side of the secondary septum, and successively decrease in size and increase in number from the centre outwards. The chambers opening all over the coral give it a most remarkable honeycombed appearance.

The columella is an elongate, thin, vertical lamina stretched in line with an opposite pair of primary septa. At its base it is provided with rootlets, which join the primary and fused tertiary septa.

In a young specimen of this coral, without reference to which the true nature of the complicated structures in the adult could hardly have been determined, the corallum is almost symmetrically biconvex and perfectly circular; but the columella is elongate, as in the adult. The columella is papillar rather than laminar, and represents the rooted base of the adult columella. There are sixty perfect costæ present at the margin of the calicle, and the commencement of two more in each system (*i. e.* twelve in all). There are twelve concentric rows of perforations in the base. The septa are not nearly so much contorted as in the adult, and the synapticular junctions between them not being as yet formed, the division of the septal cavities into successive chambers is not apparent as in the adult. No superficial fusion of the primary with the curved extensions of the tertiary and quaternary septa has as yet taken place; hence no six-rayed star or flower appears in the centre. Stout transverse granular projections are present on the upper margins of the septa, the sources of future synapticular connexions. Only four cycles are complete in each system. Two members of the fifth cycle are present in each system, and are those nearest the primary septa on each side. An additional pair of quinary septa is just commencing to grow in each system, and branching off from the peripheral ends of the quaternary septa which are next the secondary, but on that side of them which is nearest the primary, *i. e.* opposite to the secondary. A very short branch of the costa belonging to the interspace between the quaternary and secondary septa passes into each interspace formed between these newly grown quinary septa and the quaternary adjoining.

Dimensions: of an adult specimen—extreme diameter 1·7 centim., extreme height from the summit of the columella to the centre of the base 7 millims.; of the young specimen—extreme diameter 6 millims., height 3·5 millims. Three adult dead specimens and one living young one were obtained.

In the development of a flower-like series of oval chambers around the elongate columella, this coral most strikingly resembles *Stephanophyllia florealis* of Quenstedt, which is a fossil of the "White Jura" (=Oxford Clay) formation. The oval chambers here in the first series around the columella are twelve in number, and alternate with twelve in the second series. In *S. complicata*, six alternate with six. In *S. florealis* there appears to be no trace of the bisection of these chambers by the straight primary and secondary septa as in *S. complicata*; but the fossil specimens are, according to Quenstedt, always so much mutilated that their structure can only partially be made out. Possibly the twelve chambers of *S. florealis* may represent the twelve of *S. complicata*, formed by the bisection of the six inner by the primary septa, which might appear as figured in *S. florealis* in much-worn specimens. Comparison with actual specimens will determine this point. In *S. florealis* forty-eight septa only are distinguishable; but it is highly probable that structures so slight as the quinary septa of *S. complicata* might be indistinguishable in a mutilated fossil. The coral appears to fall into that division of the *Stephanophyllias* distinguished by Milne-Edwards as having the secondary septa smaller than the tertiary, and in which the tertiary septa fuse together in front of the secondary, which do not reach the centre. The coral, in fact, resembles *S. suecica*, a fossil from Ignaberga, Sweden; but in this coral the columella is rudimentary. On the other hand, Quenstedt's *S. florealis* has been supposed by Milne-Edwards to be Turbinolid, and allied to the genus *Thecocyathus*.

Stephanophyllia formosissima, sp. n.

The corallum is discoid, with the base flat in the centre and slightly curved towards the margin. It is white and very light and fragile, much more so than in *S. complicata*, being composed of a fine trabecular network, through which the light penetrates freely, as through a fine sieve, when the coral is held up to the light. The base is composed of a series of fine, radiating, costal rods connected by transverse trabeculæ, which have a general concentric disposition. The septa are composed, like the remainder of the corallum, of fused trabeculæ; but these are stouter than those composing the base, and more perfectly fused, so as to form, in most regions, continuous plates pierced by rounded perforations. There are six systems of septa and five cycles. The upper margins of the septa rise in a curve from points distant a short space from the margin of the calicle, and, ascending to some height above the level of the base, sink down again internally to the wide, oval fossa occupied by the columella.

The primary and secondary septa are straight. Their upper margins lie at a lower level than those of the remaining septa, and are only very slightly toothed. The primary septa are free from adherence. The margins of the tertiary, quaternary, and quinary septa are deeply dentate, the teeth being curved towards the columella. The quinary, quaternary, and tertiary septa fuse with one another laterally and by their upper margins at successive distances from the periphery of the corallum, forming six deltoid masses of septa. The tertiary septa, forming the sides of these deltoid masses, are bent over, sloping away from the primary septa, so that at the apex of the delta the upper margins of these tertiary septa fuse and cover over the inner ends of the secondary septa. There is no separation of the septal interspaces into chambers, as in *S. florealis*, by development of synapticulæ; but the quaternary and quinary septa are more or less bent over above, so as to fuse along part of their upper margins, and roof in the spaces between them. The septa correspond to the interspaces between the costæ. The columella is a large, oval, spongy mass composed of fine trabeculæ.

Measurements of the largest specimens: extreme diameter 3·9 centims.; extreme height 1·1 centim. Other specimens measure in diameter about 2·5 centims. and 2 centims.

This coral was obtained near the Ké Islands together with *S. complicata*, and also found living with *Euplectella aspergillum* at Cebu, Philippines, in 95 fathoms. Several living specimens have been preserved in spirit for future examination of the soft parts. In the living animal the disk is of a madder-red colour, much darker towards the margin of the calicle. The tentacles are simple and conical; the inner are white with dark madder tips, and the outer of a light madder colour with vivid emerald-green radial stripes on either side of their bases. The margin of the mouth is white. The corallum is conspicuously white, the fleshy coloured parts of the coral not extending to the very edge of the calicle. A white zone thus sets off the dark-coloured central parts of the coral.

Fungia symmetrica, Pourt.

This species of Pourtales's has been proved by our dredgings to be one of the most constantly recurring deep-sea animals with a world-wide distribution. As will be seen by reference to the list of localities, it has been dredged by us 15 times. It occurs in the North and South Atlantic, near the ice-barrier in the S. Indian Ocean, off the West Indies, in the North and South Pacific Oceans, and amongst the Moluccas. It has a more extended range in depth than almost any other animal, having been obtained by us in 30 fathoms off Bermuda, and at all intermediate depths down to 2900 fathoms. Specimens from 2900 fathoms were obtained with the soft parts preserved, and specimens from 2300 fathoms, of which 30 or more were obtained at one haul, were full of ripe ova. *Fungia symmetrica* is, further, the only coral which has been as yet obtained from a greater depth than 1600 fathoms. This coral occurs, moreover, on all kinds of bottoms—on *Globigerina*-mud in the Atlantic; amongst growing branched corals (*Madracis asperula*) off Bermuda; on a siliceous bottom, composed almost entirely of diatom-skeletons, in the South Indian Ocean; and on red clay with manganese nodules in the N. Pacific. It further sustains a range of temperature of 1° C. to 20° C. The specimens from great depths are much larger than those from shallow water, and are very delicate and fragile. Pourtales's largest specimen measured 1 centim. in diameter. We have obtained specimens measuring 3 centims. in diameter; and the specimens from the deep Northern Pacific average 2 centims. in diameter. The specimens from the diatomaceous-mud bottom were, though large, evidently growing under unfavourable conditions as regards the formation of a corallum, the bottom containing only a trace of lime; hence their coralla were so fragile that they broke at the slightest touch. From an examination of the long series of specimens of this coral obtained by us, there seems no doubt of their belonging to one species; and certain series obtained near Bermuda and the West Indies are undoubtedly identical with *F. symmetrica* as figured and described by Pourtales. The larger specimens, however, seem to show close affinities with the *Lophoserinæ*. Pourtales speaks of the near resemblance of *F. symmetrica* to *Cycloseris hexagonalis*.

Tubipora and *Madrepora nasuta*, c. f.

Dead fragments of these corals were dredged in 200 fathoms off Banda. They are instructive as showing how shore forms may be washed down into deep water.

Notes on a few Corals obtained from a less depth than 50 *fathoms.*

Madracis asperula.

This coral was originally described from Madeira. Pourtales describes it from west of Portugal in 36 fathoms, and from St. Nicholas Channel in Bahia de Cadiz in 120 fathoms. The coral occurs in great quantities on a shoal off Bermuda, known as the South-west Bank, in 30 fathoms. Masses of it came up in the dredge, and a number of specimens on fishing-lines. The coral was also dredged on the shores of St. Vincent, Cape-Verd Islands, and at Fernando de Noronha.

Flabellum variabile of Semper.

In dredging in the Arafura Sea numerous specimens of this species (which, according to Semper, includes *F. Stokesii*, *F. Owenii*, *F. aculeatum*, and *F. spinosum* of M.-Edwards) were obtained. The series shows all stages of the multiplication of this coral by fission as described by Semper *. Occurring with *F. variabile* were found *Rhodopsammia*

---

* Generationswechsel bei Steinkorallen von C. Semper. Leipzig: W. Engelmann, 1872.

socialis and *R. parallela*, which were obtained with *F. variabile* by Semper in his dredgings at the Philippines. The coral-fauna of the Philippines of moderate depths seems thus to extend southwards to the Arafura Sea; and this is borne out by the fact that in deeper water *Stephanophyllia formosissima* was obtained near the Ké Islands and also off Cebu, Philippines.

Heliastræa cavernosa.

Off Barra Grande, Brazil, two huge masses of this species were brought up by the trawl from 30 fathoms. The masses, which were of the usual convex form, measured nearly two feet in the diameter of the flat base. The corals were living. They were bored by *Lithodomi*, which, however, were dead. This is the only certain evidence obtained during our expedition of the existence of *massive reef-forming species* at so great a depth as 30 fathoms. *Madracis asperula* mentioned above is hardly a reef-forming species; but at the south-west bank, Bermuda, it is in such quantities that it must contribute to reef-formation to a considerable extent.

General Remarks on Deep-Sea Corals.

Bathymetrical Distribution.—With the exception of a *Diplohelia profunda*, a dead specimen of which was obtained from 1050 fathoms in lat. 28° 24' N., long. 79° 13' W., none of the deep-sea corals described by Count Pourtales[*] are from a greater depth than 600 fathoms; whilst only two, *Cryptohelia Piercii* and *Distichopora sulcata*, were obtained from a greater depth than 450 fathoms.

In the dredgings of H.M.S. 'Porcupine'[†] no corals were obtained from a greater depth than 1095 fathoms, from which depth *Desmophyllum crista-galli*, *Caryophyllia abyssorum*, *Solenosmilia variabilis*, and *Bathycyathus atlanticus* were obtained at one dredging. From depths of above 500 fathoms *Caryophyllia clavus*, *C. Seguenzæ*, *C. cylindracea*, *C. Inskipi*, *C. Pourtalesi*, *C. vermiformis*, *Sabinotrochus apertus*, *Bathycyathus atlanticus*, *Desmophyllum crista-galli*, *Flabellum distinctum*, *Lophohelia prolifera*, and *Fungia symmetrica* only were obtained. The yacht 'Norna' dredged off the coast of Spain and Portugal *Desmophyllum crista-galli* in 500 fathoms, and obtained *Lophohelia prolifera* in from 400 to 600 fathoms[‡].

---

[*] Illustrated Catalogue of the Museum of Comparative Anatomy at Harvard College. No. IV. Deep-Sea Corals, by L. F. de Pourtales. Cambridge, Mass., 1871.

[†] "A Description of the Madreporaria dredged up during the Expeditions of H.M.S. 'Porcupine' in 1869 and 1870," by Professor P. Martin Duncan, M.B. Lond., F.R.S., F.G.S., &c. (Trans. Zool. Soc. Lond. vol. viii. pt. 5). See also "On the Madreporaria dredged up in the Expedition of H.M.S. 'Porcupine,'" by the same author, Proc. R. Soc. 1870, vol. xxiii. p. 289; Ann. & Mag. Nat. Hist. 1870, vol. v. p. 286.

[‡] "Observations on the Madreporaria taken, in the late Expedition of the Yacht

Hence it will be seen that great additions to our knowledge concerning the bathymetrical range of corals has been made by the ‘Challenger’ Expedition. The following statements combine the results at present attained:—

Only one coral, *Fungia symmetrica*, has as yet been obtained from a greater depth than 1600 fathoms. It extends its range from 30 to 2900 fathoms.

Only three corals, *Caryophyllia formosa*, *Flabellum apertum* (c. f.), and *Cryptohelia pudica* (c. f.), have, besides *Fungia symmetrica*, been obtained at as great a depth as 1500 fathoms.

From a depth of 1000 fathoms species of the genera *Caryophyllia*, *Bathycyathus*, *Deltocyathus*, *Ceratotrochus*, *Desmophyllum*, *Amphihelia*, and *Solenosmilia* have, in addition, been dredged.

*Table showing the genera of Corals which have been obtained from a depth of 250 fathoms and upwards by:—***A**, *the American Coast Survey;* **B**, *H.M.S. ‘Porcupine;’* **C**, *H.M.S. ‘Challenger;’ with their Bathymetrical Distribution.*

Depth in fms. ...	250.	500.	750.	1000.	1250.	1500.	1750.	2000.	2250.	2500.	2750.	3000.	Age.
yophyllia	**A B C**	**B C**	**B**	**B C**	**C**	**C**	...	...	...	...	...	...	S. T.
nthocyathus, *c. f.*	**C**	...	...	...	...	...	...	...	...	...	...	...	T.
chocyathus	**A C**	...	...	...	...	...	...	...	...	...	...	...	S. T.
hycyathus	...	**B**	...	**B**	...	...	...	...	...	...	...	...	T.
cocyathus	**A**	...	...	...	...	...	...	...	...	...	...	...	S.
tocyathus	**A C**	...	**C**	**C**	...	...	...	...	...	...	...	...	T.
atotrochus	**C**	**C**	...	**C**	...	...	...	...	...	...	...	...	T.
notrochus	...	...	**B**										
mophyllum	**B**	...	**B**	**B**	...	...	...	...	...	...	...	...	T.
ellum	**B C**	**B C**	**B C**	**C**	**C**	**C**	...	...	...	...	...	...	T.
thohelia	...	...	**C**										
hohelia	**A B C**	**B**	...	...	...	...	...	...	...	...	...	...	T.
nphihelia } (?)	**B**	**B**	...	**C**	...	...	...	...	...	...	...	...	S. T.
plohelia }	**A**	...	...	**A**									
racis	**C**	...	...	**B**									
nosmilia	...	**B**											
ocora	**C**												
aster	**A B C**	**C**											
otohelia	**A C**	**A C**	**C**	...	...	**C**							
ichopora	**A**	**A**											
na	**A**												
dopora	**A**												
nophyllia	**B C**	...	...	...	...	...	...	...	...	...	...	...	T.
opsammia	**A**												
lrophyllia	**A**	...	...	...	...	...	...	...	...	...	...	...	T.
gia	**A C**	...	**B C**	**C**	**C**	...	**C**	...	**C**	...	**C**		
ophyllia	**A**												
othrius	**A C**												

‘Norna,’ off the Coast of Spain and Portugal,” by W. Saville Kent, Ann. & Mag. Nat. Hist. 1870, vol. vi. p. 459.

* *Diplohelia profunda* (Pourt.) is believed to be identical with *Amphihelia ramea* by Prof. M. Duncan.

Besides *Fungia symmetrica*, the genera *Caryophyllia*, *Flabellum*, and *Cryptohelia* are remarkable, but in a less degree, for their wide bathymetrical range.

Only about 27 genera of corals have as yet been proved to exist in a depth of 250 fathoms and upwards. A list of these genera is here given (p. 565), compiled from the reports of Count Pourtales and Prof. Martin Duncan, and from my own notes. The various depths at which the genera have been obtained are shown in columns. The letter **A** represents that the coral was obtained by the U. S. Coast Survey at the stated depth, **B** that it was dredged by H.M.S. 'Porcupine,' **C** by H.M.S. 'Challenger.' In the last column S. denotes that the genus occurs in Secondary formations, T. in Tertiary beds.

Geographical Distribution.

The extraordinarily wide distribution of *Fungia symmetrica* has already been referred to. *Cryptohelia pudica* occurs off the Canary Islands, off the West Indies, off Bahia, in the South-west Pacific, and off the coast of Japan. *Flabellum apertum* occurs off the coast of Portugal and off the Marion Islands in the South-Indian Ocean. In this respect deep-sea corals agree with almost all other deep-sea animals—the same forms of starfish, sponges, crustacea, &c. having turned up in the dredge over and over again in all parts of the world from deep water with tedious reiteration. Some deep-sea corals, however, appear, as far as our present knowledge goes, to be remarkably limited in distribution, and some groups to be specially developed in particular places. It is remarkable that Pourtales does not record the occurrence of a single *Flabellum* amongst the corals obtained by the U. S. Survey. No *Flabellum* was obtained in the corresponding region by the 'Challenger.' One apparently abnormal specimen, here described as *Flabellum angulare*, was obtained not far from Halifax, Nova Scotia, but none in the West-Indian region. Various species of *Flabellum* have been dredged by the 'Challenger' in deep water in all parts of the world, and two species were obtained by the 'Porcupine.' It is further singular that only one Stylasteracean was obtained, and at only one dredging, by the 'Porcupine.' Pourtales describes seven genera of this group and eleven species obtained from deep water, most of them from 270 fathoms, off Cuba, where this group seems to be especially developed. We have dredged specimens of the group at least eight times. A considerable number, however, of the species of deep-sea corals dredged by us have been obtained very seldom indeed and in few specimens, in several cases only one specimen having been obtained. Thus of *Trochocyathus coronatus* Pourtales received only one mutilated specimen from off the coast of Florida, whilst we dredged five specimens on one occasion only off St. Thomas. Of *Ceratotrochus diadema* two specimens only have been dredged at two localities in the Atlantic. *Ceratotrochus platypus*, *C. dis-*

coides, and *C. nobilis* have been dredged but once, two specimens of the first of the three having been obtained, and only a single one of each of the others. *Ceratotrochus platypus* was obtained off the coast of New South Wales; the other three species of *Ceratotrochus* in the Atlantic. These *Ceratotrochi* appear not to occur in the Pacific, nor in the seas of the East-Indian archipelago and Philippines. In the deep waters about the Philippines and near the Ké Islands their place seems to be taken by the *Stephanophyllias* and *Platytrochus rubescens* and *Deltocyathus magnificus*.

Families and Genera of Corals occurring in the Deep Sea.

The following is a list of the genera of corals as yet obtained from the deep sea from depths of 50 fathoms and upwards, compiled from Count Pourtales's and Professor Martin Duncan's works, and from the preliminary determinations of our own series made by myself, which will, however, I expect, need some modifications hereafter, but not such as very materially to alter the results.

List of Genera of Corals obtained by the U. S. Coast Survey, H.M.S. 'Porcupine,' and H.M.S. 'Challenger,' in depths of 50 fathoms and upwards.

TURBINOLIDÆ.

Caryophyllia. S. T.
Cœnocyathus. S.
Acanthocyathus. T.
Bathycyathus. S.
Stenocyathus (*Pourt.*).
Trochocyathus. S. T.
Thecocyathus. S.
Leptocyathus.
Paracyathus.
Deltocyathus. T.
Sphenotrochus. T.
Platytrochus. T.
Ceratotrochus. T.
Sabinotrochus (*Duncan*).
Desmophyllum. T.
Flabellum. T.
Rhizotrochus.

OCULINIDÆ.

Oculina. T.
Cyathohelia.
Lophohelia. T.
Amphihelia. S. T.

STYLOPHORIDÆ (Pourt.).

Madracis.

ASTRÆIDÆ.

Parasmilia. S.
Cœlosmilia. S.
Solenosmilia (*Duncan*).
Astræaceæ (genus of).
Cladocora.

STYLASTERIDÆ (Gray).

Stylaster.
Allopora.
Cryptohelia.
Distichopora.
Errina.
Lepidopora (*Pourt.*).

EUPSAMMIDÆ.

Balanophyllia. T.
Stephanophyllia. S. T.
Thecopsammia (*Pourt.*).
Dendrophyllia. T.

FUNGIDÆ.

Fungia.
Diaseris.

MILLEPORIDÆ.

Pliobothrus.

RUGOSA.

Haplophyllia.
Guynia.

Note.—S. after the name denotes that the genus occurs in Secondary formations, T. in Tertiary formations.

From the foregoing list it will be seen that 17 genera out of 42 obtained hitherto in depths of 50 fathoms and upwards belong to the Turbinolidæ; and if, following Pourtales, we placed with the Turbinolidæ the genera *Parasmilia*, *Cœlosmilia*, and *Solenosmilia*, there would be twenty genera of Turbinolidæ. The family next most abundant in genera is that of the Stylasteridæ, which has six genera in the list. Further, twenty-six of the genera in the list are those of simple corals, and only sixteen genera of compound forms. The excess of the genera of the Turbinolidæ is what might be expected, since this is the family which contains most extratropical shallower-water forms, and which may thus be supposed to be best suited to low temperatures at considerable depths. With regard to the genera and species procured by the 'Challenger,' it will be remarked that the genera *Cænocyathus*, *Acanthocyathus*, *Platytrochus*, and *Ceratotrochus* amongst the Turbinolidæ are new additions to the deep-sea coral-fauna. The four species described under the genus *Ceratotrochus* may give rise to one or two new allied genera. Amongst the Oculinidæ, *Cyathohelia* is new to the deep sea. Amongst the Astræidæ the occurrence of a genus of Astræaceæ at 126 fathoms is remarkable and quite exceptional. The coral is a very small and dwarfed form, of which I have not determined the genus; it occurs also in the Arafura Sea in 49 fathoms in company with *Flabellum variabile* and *Rhodopsammia parallela* and *socialis*. Amongst the Eupsammidæ the genus of *Stephanophyllia* is a new phenomenon, and the two species obtained appear to be of great interest, and likely to throw much light on fossil forms.

On the occurrence of Fossil forms in the Deep-Sea Fauna.

Of the forty-two genera on the list just given twenty occur in the fossil state. Eight of these occur in Secondary formations, viz. *Caryophyllia*, *Bathycyathus*, *Trochocyathus*, *Thecocyathus*, *Amphihelia*, *Parasmilia*, *Cœlosmilia*, and *Stephanophyllia*. Of these, two extend into the Jura formations, viz. *Trochocyathus* and *Cœlosmilia*; the remainder are not known from earlier deposits than the chalk. The remaining genera of the list are known only from Tertiary formations. Of these twenty genera, however, thirteen were known before deep-sea dredging commenced, to occur both in the recent and fossil condition, and hence they must occur in not very deep water, whilst some of them, as *Caryophyllia* and *Flabellum*, occur in very moderate depths. Seven of the fossil genera, viz. *Trochocyathus* *, *Thecocyathus*, *Deltocyathus*, *Platytrochus*, *Ceratotrochus*, *Parasmilia*, and *Stephanophyllia*, have been added to the list of fossil genera, which have survived to the present epoch, by deep-sea dredging. Of the twenty fossil genera above referred to, thirteen only occur at so great a depth as 250 fathoms, eight are found at 500 fathoms, seven at

---

* *Trochocyathus philippensis* (Semper), however, occurs at the Philippines in from 15-30 fathoms.

1000 fathoms. Some of the most interesting forms, such as *Stephanophyllia*, occur at small depths (120 and 92 fathoms); whilst *Haplophyllia* and *Guynia*, believed by Pourtales and Duncan to belong to the Rugosa, are from 324 fathoms and 92 fathoms respectively. The most widely distributed and most abundant deep-sea coral, which extends to nearly twice the depth to which any other coral attains, viz. *Fungia symmetrica*, belongs to a genus which is not known to occur in the fossil state*. The whole family of the Stylasteridæ, of which six genera occur in the deep water (one of them, *Cryptohelia*, being one of the only four genera which extend to a depth of 1500 fathoms, and the only compound coral amongst these), is recent only.

No coral in any way allied to the Rugosa has been dredged by the 'Challenger.'

IV. Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Observations made during the earlier part of the Voyage of H.M.S. 'Challenger.' By the late Dr. RUDOLF VON WILLEMÖES-SUHM, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876. Read March 16.

On our way from England to Lisbon we had continually very bad weather, and could hardly do any thing but put books and instruments into their proper places. In Lisbon we paid frequent visits to the Museum, the fauna of Setubal (near the capital) being particularly interesting, as it is one of the few places in which deep-sea animals go up into shallower water and are accessible to fishermen. Professor Barboza showed us the *Hyalonema* which had been got there, and pointed especially to the sharks and Chimæridæ which have been discovered near Lisbon. On our way to Gibraltar we had some dredgings, but were in the latter place more busy at getting up the catalogue of books and instruments, which since that time has been printed by order of the Admiralty. We also visited nearly daily the Gibraltar market, without, however, finding any thing that was particularly interesting.

Only when we left this port we got into proper working order; and I began to examine more especially the worms which were brought up, a class to which I had paid much attention before joining this expedition, more especially the Annelids and Gephyreans. I made sketches of the former, and was, however, very much astonished to find that they all agreed very much with the genera of shallower water—a fact which has since been corroborated by Professor Ehlers's interesting paper on the Annelids collected in H.M.S. 'Porcupine' and 'Lightning,' as well as by our own experience during our stay in the 'Challenger.' Though I afterwards did not examine them with so much care as at the beginning, I nevertheless have continued during the whole time to collect them as well as possible, and to examine those which wanted to be drawn when alive or which seemed to be particularly interesting. To the latter forms I shall refer in the course of this report.

---

* Future comparison of specimens may, however, show a relation between some of the varieties of the species here called *F. symmetrica* and some Lophoserinæ.

Of the Gephyreans I have worked out immediately all those forms which were not quite common Sipunculids, and shall give a short account of them below.

The other classes of worms (*Balanoglossus*, Nemerteans, *Polygordius*, Nematodes, &c.) have been met with rarely in deep water, but have all the more been taken care of.

Having caught, on our way from Gibraltar to Madeira, a large female of *Cystisoma Neptunus*, and been able to work out the then perfectly unknown structure of both sexes of this interesting Amphipod, my attention was drawn towards the Crustacea, all the more so as the dredgings from deep water brought up forms which proved to be of the highest interest and peculiar to those depths. These I have, as far as they were anatomically interesting, worked out during our cruises in the Atlantic and the Antarctic, when I found that I had laid a good foundation to our knowledge of the deep-sea Crustacea, and that after that new forms or new and peculiar genera (as far as their anatomy or zoological position goes) rarely turned up. These researches, as far as the Atlantic Crustacea are concerned, have been presented in a paper to the Linnean Society (Linn. Trans. 2nd ser. Zool. vol. i. pp. 23–59, pls. 6–13).

The surface Crustacea had of course during that time also attracted my attention, and had been always collected; but only in the Antarctic and in the Pacific, when I had more time to bestow upon them, I began systematically to work out the development or the anatomy of all those forms which seemed to me especially interesting.

Many drawings and notes have of course also been made on other surface animals, especially Pteropods, mollusks, &c.; and they have, as far as I was able to determine them, been put down in the "surface-book" on the days when they were found.

This surface-book, as well as the "*station-book*," have been during the whole time under my charge, as I also had to bottle and label the Invertebrates which were brought into the laboratory.

Whenever we were in harbour, and the place was little- or unknown, I had to collect the Invertebrata, especially land-shells, insects, Crustacea, and worms, in which excursions I took of course as many of the Reptilia or other Vertebrates as could be procured. Shooting birds has been done by me in some places, especially in the South-Sea Islands, but never regularly, and more for recreation than for collecting systematically.

In the following pages I shall try to give a preliminary account of the more interesting animals which were got in the dredgings, so far as they fall under the above-mentioned categories, then say something on the surface-animals, and finally on the result of my excursions on shore.

THE ATLANTIC.

Here and there on the coasts of the Atlantic deep-sea animals have been found either washed on shore or floating dead on the surface of the sea. Certain Crustacea and fish on the coasts of Madeira and the Mediterranean, *Umbellularia* and *Cirroteuthis* in the high north, were animals considered very rare, and about the habitat of which nothing certain was known. Much of this uncertainty has been cleared up by the three successive English dredging-expeditions; and I shall give at the end of this report a short statement regarding those animals known before deep-sea dredging began systematically. There is in the Atlantic only one place in which *Hyalonema* had been of late years regularly found, and this was considered to be a place, like Japan, where alone this sponge genus might be procured. Since that time matters have greatly changed, especially as far as the distribution of the glassrope sponges goes; for now we know that genera like *Hyalonema*, *Euplectella*, *Aphrocallistes*, *Farrea*, &c. are the most characteristic inhabitants of the great depths all over the world, and with them ordinary siliceous sponges, some of which rival the Hyalospongiæ in beauty.

Umbellularia was found three times in the Atlantic after the Swedes had rediscovered this genus, which nearly a century ago had been found by a whaler on the coasts of Greenland. Professor Kölliker has already worked out this species, which he considers to be different from the northern one. *Alcyonaria* and *Antipathes* have also been constantly brought up, and the latter is especially characteristic of great depths.

We owe to American expeditions a good deal of what was known about the bathymetrical distribution of corals and of Echinoderms; but especially the latter have during this 'Challenger' expedition yielded a very large variety of species, the greater part of which is very likely new and has partly been described already by Professor Wyville Thomson. I have been greatly interested in Crinoids for the sake of their parasites (*Myzostomum*), most of which were, however, got only in the Pacific; and I shall say a few words about their very extraordinary mode of living when giving an account of the worms found in that ocean.

The *Platodes* are a group which has been rarely met with; here and there of course Cestodes or Trematodes in young or old stages might be found inhabiting the invertebrates and afterwards the fish; but nothing has come to my knowledge about them, as the latter were far too precious to be dissected for helminthological purposes. Nemerteans do go down to great depths; but they were rarely got here, only once off the coast of Brazil, in 1200 fathoms; and the worst is that when you do get them they are generally in pieces, either by friction among stones and mud or

Google

by breaking themselves up into small pieces like certain *Synaptæ*. Of *Rhabdocœla* and *Dendrocœla* I never saw a trace; but they are still more liable to be spoiled or overlooked than the former.

There are, I think, a few free Nematodes; but certainly they are very scarce. Of great interest is, however, a case of parasitism, which may be compared to the attacks which on shore the young *Gordii* make on our grasshoppers. I found once in a shrimp from a great depth a worm coiled up in its carapax, and afterwards the same thing when on our way to New Zealand; and we made sure that the worm which was contained in the second shrimp was a young Gordiacean. During our Antarctic cruise we have also got two free-living Nematodes, which we suspect very much to be the mature animal; anyhow it is quite certain that shrimps in great depths are liable to be attacked by considerably large Gordiaceous worms.

Of Bryozoa there is a great variety in nearly all depths where animals have been found; but only one of them, being a very striking form and differing in its features from the hitherto known species, has attracted our attention and been described by Professor Wyville Thomson under the name of *Naresia cyathus*. It has been got three times, in 350, 1525, and 1950 fathoms, near the coasts of Portugal, as well as off those of Brazil. In the dredgings near the latter coast the fauna of Bryozoa was especially rich.

Gephyreans were got now and then, especially in cases where a great deal of mud had been brought up. Whether their first order, the chætiferous ones, are represented in our collections of the Atlantic (we consider, of course, *Sternaspis* to be an annelid) is uncertain, as I find mentioned on our list only a fragment, which might be ascribed to *Echiurus*, from 39 fathoms, and a very large worm, perhaps allied to *Bonellia*, with which it shares the presence of only one genital pore, but which has lost the anterior portion of its body. The consequence is that we are unable to find out whether hooks have been present or not; anyhow this specimen, which has a length of 76 millims., and which came up off Nova Scotia from 1340 fathoms, is a very interesting one.

The unarmed Gephyreans were more commonly got. Of the genus *Priapulus* we had a specimen from 2750 fathoms on our way from Bermudas to the Azores; and *Chætoderma* (Lovén's curious little worm with calcareous spines in its skin) was found twice in depths of 390 and 1250 fathoms. I was rather astonished never to find *Halicryptus*, as I had expected that this genus, which inhabits the Baltic and the high north, would be very common in deep water.

A curious intermediate form between Priapulids and Sipunculids came up from 1945 fathoms off the island of Ferro. This worm has no tentacles and no proboscis like the former, but has at the same time the anus in the anterior part of its body (Sipunculids). Its pharynx is very short, and is attached to the body by four retractores. Its inside shows six to seven folds, and is covered with papillæ, which towards the mouth change into chitinous protuberances. In each of these one finds some unicellular glands, granulated cells showing a nucleus and a nucleolus. Unfortunately the posterior portion of its body had been destroyed before we got it.

The commonest Gephyrean genus is undoubtedly *Sipunculus*, in shallow water as well as in deep water; we got it here three times, in depths from 350 to 2500 fathoms.

We have been particularly looking out for *Phoronis*, but have never been able to find it, and feel now nearly sure that it does not inhabit, as a rule, the great depths. *Sternaspis*, however, has been got in 1700 fathoms of water, and besides this annelid another form (600 fathoms off Gomera), which has an intestine coiled up like that of a Gephyrean, and only three pairs of setigerous feet in the posterior portion of its body. It is in many ways peculiar; but I am unable as yet to determine its systematical position from want of books of reference.

Among the tube-building annelids the Clymenidæ, Terebellidæ, and Serpulidæ are characteristic inhabitants of great depths, and go, like that *Myriochele*, sp., which I have figured ('Nature,' 1873), to a depth of 2900 fathoms. We missed *Chætopterus*, *Siphonostomum*, and *Pectinaria*, which for various reasons we had expected to find in rather deep water. Of free-living annelids, however, there is a large amount, Aphroditidæ, Palmyridæ, Eunicinæ (*Onuphis* is very common), and Glyceridæ being the families chiefly represented. I found that sometimes genera which have got eyes in shallow water are represented by a blind species in deep water—an observation which, I think, has also been made by Professor Ehlers.

Having described shortly before I joined this expedition a northern form of *Balanoglossus* (*B. Kupferi*, from the Oeresund near Copenhagen, 14 fathoms), I was of course greatly interested in a large fragment of this peculiar worm which came up near the west coast of Africa from 2500 fathoms. Unlike its northern cousins, this species has very bright colours, its head being yellow, its collar bright red, and its body yellowish red. The head alone has a width of 18 and a height of 11 millims. In deep water this genus was seldom again obtained; and I may therefore now mention that in most tropical places in the Pacific I found this genus to be an inhabitant of the shallow water, as I constantly found the larva known under the name of *Tornaria*, and sometimes such stages of its development which have been shown by Mecznikoff and A. Agassiz to belong to *Balanoglossus*.

Parasitical Cirripedia are by no means rare on the shallow-water shrimps, and are found as well among those coming from great depths. We have noticed a *Peltogaster* here and there, but feel sure that a careful examination of the Macrurous Decapods will show many more cases.

Both groups of the Cirripedia Thoracica are well known in a fossil state;

and it is not uninteresting to find that *Balanus*, a crustacean which was eminently developed in the Tertiary formation, is now nearly entirely confined to shallower water, but that the Lepadid *Scalpellum*, which is mostly found in the Cretaceous formation, is now-a-days widely spread in the greater depths. Indeed it has been the only Cirriped which we have often met in depths from 925 to 2850 fathoms, and was got in the Atlantic six times, one of them having been described by Professor Wyville Thomson under the name of *Scalpellum regium* ('Nature,' 1873).

Of free-living Copepods there are none on our list, nor do I think that any are living below the range of the so-called surface-animals; but their parasitical relations are found as well on the deep-sea fishes as on those from shallower water—as, for example, on a Lophioid allied to *Ceratias*, which came up from a depth of 2400 fathoms, and is sure, from the mode of living peculiar to that group of fish, to have come from the bottom.

There are no Ostracoda to be mentioned here; and of Amphipoda (which, however, are by no means wanting in deep water) only one specimen of *Eusirus cuspidatus* has been put down by me; but perhaps some more might be found among the siftings.

Very peculiar are the deep-sea Isopods; for besides the ordinary *Arcturus*-form which we got from 450 fathoms, there is a very peculiar family of which Sars has described five genera from the Norwegian coast, all of which are blind. The body is divided into two portions; the anterior one, consisting of a head with four segments of the pereion, is short, and the posterior, consisting of the three remaining pereion-segments, rather long. The first pair of legs is short and prehensile; but the three following pairs have an extraordinary length, and are very thin and slender, and the last three pairs are terminated by paddle-shaped joints and act as natatory organs. Very peculiar is also their abdomen, which consists of only one segment, on the end of which we find two small setigerous papillæ. Of these Munopsidæ, the legs of which break unfortunately very easily, we got a large and very soft species from 2175 fathoms on our passage from Bermudas to the Azores, and another spiny species not far from there from 1675 fathoms.

When dredging off the coast of Brazil near Pernambuco we fell in for the first time with an Isopod, which, from a superficial resemblance with the fossil Trilobites, has enjoyed for some time a certain notoriety; I mean *Serolis*, the flat crustacean which has long been known as inhabiting the southern coast of America. We never found it again in the tropics, neither in deep nor in shallower water, but shall have to mention it frequently among the Crustacea of the Antarctic.

A blind *Tanais* was brought up from 1400 fathoms.

Cuma, which, according to Claus, has its nearest relations among the Isopods, is not common in deep water, and was found only once in 1000 fathoms near San Miguel, Azores.

Stomatopoda are entirely confined to the shallower water of the tropical and temperate regions. We never met with one far away from the land, though their young stages are widely spread all over the surface of warmer seas.

The most interesting Crustacea which have been got are undoubtedly the Schizopods, several new genera of which were brought up, which are both interesting for anatomical and physiological reasons. These have been partly figured in 'Nature' (*Gnathophausia*, 'Nature,' 1873), and afterwards fully described by me in a paper "On some Atlantic Crustacea," which has been or will be published by the Linnean Society. Here only a few words about them.

The normal Schizopods, as is well known, have their carapax fixed to the pereion, with the exception of the aberrant genus *Nebalia*, in which the latter is unattached, and resembles a shell enclosing the anterior portion of the body. Our deep-sea genera, however, have (at least most of them) a carapax which is neither the one nor the other, but resembles very much the shield-like carapax of the Phyllopod genus *Apus*. In other respects they are, however, nearly allied to the established families, though some of them have characters which are peculiar to several of the shallow-water forms, but have as yet not been found united in one genus. Moreover some of these abyssal Crustacea are blind, or show peculiar modifications of the organs of sight, as well as of the chitinous outer parts, which have lost the optical apparatus.

Petalophthalmus inermis is the name which I have given to the most remarkable of these Schizopods, as in it the optical apparatus of the eye is entirely wanting, while its chitinous parts have remained in the shape of a concave plate-like organ supported by a peduncle. This plate shows neither a trace of the organs of vision nor any appendages; it consists of a double chitinous layer, and nothing is to be seen in it but the fluid of the body and the attachment of the muscles, which are to be found in all stalked-eyed Crustacea. Its appendages show this form to belong to the family Mysidæ, there being six legs (second gnathopod and the five pereiopods), no branchiæ, large breeding-lamellæ in the female, and only rudimentary pleopods in the male. The carapax, as we have said above, leaves in both sexes five segments entirely uncovered.

But besides the looseness of the carapax there are peculiarities in the male of this Schizopod which have been found nowhere else; for its first antennæ, the palpus mandibularis, the maxilliped, and the first gnathopod have been converted into enormous prehensile organs, and the latter shows a large lamellar appendage like the maxilliped in the female. These elongated appendages have in the male six times the length which they have in the female.

This is the only Mysid which was got from great depths (1900 and 2500 fathoms). The next family, the Euphausiidæ, was represented by a very large species, red and opaque, which came up in the South Atlantic from a depth of 1900 fathoms. It is in so far remarkable as it was in the Atlantic the only Schizopod in which the carapax is attached to the posterior segments of the pereion.

The most characteristic Schizopods in great depths belong to the Lophogastridæ, from which they differ, however (like *Petalophthalmus* from the shallow-water Mysidæ), by the looseness of the shield, and by a pair of lateral eyes, which hitherto were only known among the Euphausiidæ. These lateral eyes, however, in *Gnathophausia* never exceed two in number, and are invariably fixed on the outer margin of the second maxilla. The carapax here is bent backwards, and thus leaves a place open, which enables these sense-organs to perform their duty.

In all other respects these Schizopods are true Lophogastrids, some of them, however, exceeding very much in size the small shallow-water species (*L. typicus*) which Sars has described from the Norwegian coast. There are three species:—1. *Gnathophausia gigas*, length 142 millims., found only once in the Atlantic from a depth of 2200 fathoms near the Azores. It is not impossible that this is the animal which Dohrn has got in a very badly preserved state from the coast of Africa (without any appendages, and evidently somewhat crushed), and described under the name of *Lophogaster ingens*. He does not, however, mention the eyes on the second maxilla, and says that the carapax *was* fastened to the pereion; and for this reason I have to wait until I can myself compare the specimen in the Hamburg Museum with those caught by us. This would of course in no way affect the validity of the characters upon which the genus *Gnathophausia* has been established, but induce one to put the specific name of *Gn. ingens*, Dohrn, instead of *Gn. gigas*, mihi. 2. *Gn. zoëa*, a smaller form, length 60–80 millims. This species is the commonest Schizopod, as we got it five times from 1000–2550 fathoms. Many males and females have been caught, and its anatomy has been thoroughly worked out. 3. *Gn. gracilis*, a still smaller spiny species, of which only one specimen was got from 1500 fathoms, not far from the rocks of St. Paul.

A third genus in which the carapax is not attached is *Chalaraspis*, which has got very long walking-legs with large claws to them (*Ch. unguifer*), and is most nearly allied to the Lophogastridæ, though it may perhaps be necessary to establish for it a new family. Its organs of vision offer nothing particular. I must refer about further details to my above-mentioned paper, and can here only state that it was got four times, in depths of 350, 675, 1850, and 1900 fathoms, in the Middle and Southern Atlantic.

Decapoda Macrura were very common: nearly every haul brought up Peneids and Caridids, sometimes of large size and having often a very peculiar look; but I do not think that any thing very interesting, except a series of new forms with a more or less spiny carapax and longer or shorter legs than usual, will be found among them.

In a very successful dredging in 450 fathoms off St. Thomas we got an Astacid, which I have described and figured under the name of *A. zaleucus*, as it is totally without eyes or even a trace of eye-stalks, and is distinguished by an enormous development of the right claw. The animal has never been got since, but may perhaps, when a female shall have been found, form the type of a new genus. In the mean time I have called it *Astacus*, as it seemed to be nearer to the crayfish than to *Nephrops*, to which it would be convenient in so far to put it, as this genus contains only salt-water forms. This is a question which has to be decided by those who, after us, will be fortunate enough to dredge up some more specimens of it.

Another Decapod, of which two species were got in the Atlantic, is *Willemöesia*, a genus established by Grote, and first described by us under the name of *Deidamia*. I have shown in my paper that these crayfishes are so nearly allied to the fossil Eryonidæ (from the Solenhofener Schiefer), that it becomes doubtful whether a new genus is to be established for them at all. If, as lately has been maintained by Mr. Wood-Mason, these Crustacea have already been described by Heller under the name of *Polycheles*, from a specimen which was got in the Mediterranean near the coasts of Sicily, this will of course be the name to be adopted. I am unable for the present to compare Heller's figure with our specimens, and shall have to reconsider the question when working out the Crustacea of this expedition. There are some points in Heller's description which still make me doubtful about it; and in order not to confuse the matter more, we shall call these Crustacea *Willemöesia* until we return to Europe. Anyhow, it is very interesting *that cousins of the famous Jurassic Eryonidæ are still living in the great depths, where they are* (in the Pacific at least) *by no means rare.*

The two species found in the Atlantic are both blind: one of them, *Willemöesia leptodactyla*, has been only found in very great depths; the other one, *W. crucifer*, was brought up off St. Thomas (W. I.) from a depth of 450 fathoms. We shall below have to mention a third species, which we have very often got in the tropical parts of the Pacific.

Of Palinurids we got here only one form, a small species with eyes partly hidden under the rostrum, which I shall only describe after our return, as it might possibly be known already.

The anomurous Crustacea *Pagurus* and *Galathea* are very common in deep water, especially the former, which very often carries about a large *Palythoa*, which itself has nearly absorbed the calcareous substance of the shell on and in which both animals originally settled. The *Galathea* has been got with and without eggs; and it appears that one whitish species, which inhabits the great depths, is to be found in all the seas.

Brachyura were very rarely brought up; we had once, from 600 fathoms, a very large red crab, and from 1675 fathoms a blind spiny larva of a crab, which was in the *Megalopa*-stage, and is all the more interesting as young stages of deep-sea animals do not often occur, owing to their small size, by which they escape through the net or are hopelessly lost in the mud.

We got once a *Lupea* and a *Gecarcinus* on the coast of Brazil from a depth of 350 fathoms; but these can scarcely be considered deep-sea animals. It is, however, remarkable to find that *Gecarcinus*, a genus which lives in holes on shore, should ever go for breeding-purposes to such a considerable depth as that, unless we here have a species before us which has taken to sea-life—a return to old habits which is neither known among the Telphusidæ nor the Gecarcinidæ, but which, of course, is not altogether out of question.

Naturalists who have dredged much in shallow water are accustomed to consider *Nymphon* as a form which lives above the bottom, climbing up into the *Fucus* and never burrowing into the mud like *Pycnogonum*, also to find the latter in greater depths than the former; at least these were my experiences on the northern coast. But in the deep sea just the reverse is the case; *Pycnogonum* is either very rare or altogether wanting there, while *Nymphon* and the allied genera *Zetes* &c. are pretty common, and evidently walking gravely with their long legs over the muddy bottom. In the Atlantic we got *Nymphon* from 1250 and *Zetes* from 350 and 1075 fathoms, none of them being particularly remarkable, either for size or any thing else. Some of the females had the well-known larval forms, which by Claparède and others have been sufficiently described.

Brachiopoda were on the whole scarce. We had once a very large *Waldhemia* with exceedingly small animal, which was got on our way from Gibraltar to Madeira from 390 fathoms, and several times some small Brachiopoda from 850 to 1000 fathoms, the genus of which was not determined.

Also Ascidians were by no means common. Though the true genus *Ascidia* (transparent Tunicata without a stalk, taken in the wider sense) does occur in great depths, I do not remember its having been found in the Atlantic, where only a very fine species of *Boltenia* was found near the coast of North America in 1700 fathoms.

The Lamellibranchiata and Gastropoda have been duly collected and preserved; but I am not able to say much about them. "Fine shells" there are scarcely any; if they come up at all, they are small and of ordinary appearance like *Arca*, *Neæra*, *Pleuronectia*, *Trochus*, *Fusus*, &c. *Dentalium*, about the most interesting of all of them, goes to great depths, and was, either alive or dead, nearly always found when great quantities of mud were brought up by the dredge.

Of Cephalopoda I find only an *Eledone* on my list, which, coming from 350 fathoms, belongs, however, to the shore-fauna of Brazil. All the other species of the Atlantic belong to its transparent surface-forms; and I am not quite sure whether *Cirroteuthis* is not the only Cephalopod which goes to considerable depths. This one, however, was brought up only later.

Everybody who for some time has been in the habit of visiting the fish-markets of the Mediterranean knows how great a rarity the "grenadier-fish" (*Lepidoleprus* or *Macrurus*) is considered to be by the fishermen of those shores, and how little was known as to where those curious Scopelids *Sternoptyx*, *Chauliodus*, and others might live. The latter are washed on shore from time to time, and are sure to come into the hands of naturalists, as the fishermen know their value. In the Italian fish-markets they were all the more eagerly looked after, as Professor Leuckart had described in them a sort of sense-organs running along both sides of the body, which he considered, with some doubt, to be organs of sight. But the supply was scanty, and very few zoologists who paid a visit to these places were able to get them.

Now these riddles are solved; for we know that *Macrurus* is one of the commonest inhabitants of the depths, and that with them the Sternoptychidæ very generally come up. Like other deep-sea animals and those specimens which from time to time were washed on the shores of Italy and Madeira, we have also found them occasionally floating about on the surface of the sea; and one species, a small, elongate, blackish fish, at least seems to belong to the pelagic fauna; but the majority, especially *Sternoptyx* and *Chauliodus*, are so rarely got on the surface, and so constantly brought up from greater depths, that I must regard them as inhabitants of that zone.

One of the Scopelids which came up from great depths (1600 and 1900 fathoms) in the Atlantic is very peculiar for its blindness and its flattened head, on the top of which there is a peculiar sense-organ of a silvery colour, 10 millims. long and 9 millims. wide. I examined this organ at that time with a lens, and it seemed to me to consist of three layers:—1, a very thin transparent epidermis; 2, a layer of hexagonal small columns resembling in miniature the lateral electrical organs of a *Torpedo*; and 3, a silvery tapetum. Without giving any opinion about the nature of these peculiar organs, I should like to point out the analogy which seems to me to exist between them and those organs which Leydig has figured from the scales of certain Reptilia in Max Schultze's 'Archiv,' 1873.

This fish was afterwards also got in the Pacific.

Of the other inhabitants of the depths (the Ophidiids, Lophioids, &c.) I have little to say, especially as, after our leaving the Atlantic, these fish were preserved in the upper-deck laboratory, where I have only seen but never studied them.

Surface of the Atlantic.

Only a few of the Atlantic surface-animals have been worked out by me; and about them I shall say a few words when discussing their relations of the Pacific. I do not think it advisable to fill up this report with general remarks on a fauna which is so well known as the surface of the Atlantic.

The Islands of the Atlantic.

On our first visit to the Madeira fish-market we got a number of *Mora mediterranea* specimens, a fish which we had got a few days before in deep water. We also secured a fine *Beryx*, which, being one of the oldest genera of Acanthopterygians, is especially remarkable.

In St. Thomas we spent a few days after a four weeks' cruise, but did little in the way of collecting, except catching some fish in the trammel and some dredging. The Professor secured in this place a great number of Echinoderms.

Numerous excursions were made in Bermudas, partly inland, when I tried to catch as many insects as possible on the beach, where the shallow-water animals were secured by wading. Hungary Bay was my chief place of resort. Here the forest approaches the beach, and afforded opportunities for collecting of all kinds. There mangrove-trees were growing in large swamps, crowded with a *Grapsus* which ascended these trees; and under the stones which covered the muddy ground I found plenty of land-crabs belonging to different genera of the Telphusidæ. When looking for these I discovered a land-Nemertean, being the first one found in the western hemisphere (the only animal of this kind having been found by Semper in the Philippines). This species was described and figured in the 'Annals and Magazine of Natural History' for 1874 (xiii. p. 409), under the name *Tetrastemma agricola*.

In Bermudas we also made frequent excursions in the steam-launch, which enabled me to get specimens of a *Nebalia* which I had noticed before among Crustacea collected by Mr. Murray. This species (*N. longipes*), which I have worked out and described in the 'Transactions of the Linnean Society,' is remarkable in many ways, as its legs are far less "phyllopodal" than in the other species known before, and, as in the male of this American *Nebalia*, it is the first and not the second antenna (*N. Geoffroyi*) which has been enlarged and transformed into a prehensile organ.

In the Azores we had only a few days, and in Madeira there was no landing on account of the small-pox being there. Our next collecting-places were the Cape-Verd Islands, first St. Vincent and then St. Iago.

In the barren island of St. Vincent I made a trip into the mountains, and was very much struck by the utter barrenness of the place. *Cathartes percnopterus*, crows, and a few small birds were the only living beings we saw flying about. Under stones we got some geckos (*Platydactylus*) and a *Lycosa*, and near a water-pool a few dragonflies were seen. These were, with the exception of a few beetles, the only animals which could be found, though we looked about a good deal.

In the mean time Mr. Moseley had found out that there were certain spots in the valleys where the tamarisks grew higher than in other places and in clusters, forming a small oasis in this desert place, and that these are the places round which the insects assemble in considerable numbers. Here a *Myrmeleon*-larva eagerly watches the ants, large colonies of which are to be found. Its imago was also found, folding its wings, when settling, like a *Perla*, and when flying very much resembling an *Agrion*, a genus which was not found in these places. Some Ichneumonids (especially a large black species with yellow antennæ) and many Diptera (especially an *Osmia*) are to be seen; and of Orthoptera there are small and large *Acridia* and a *Gryllus* burrowing under the stones. Of Coleoptera we got perhaps fifteen to twenty species, most of which belong to Melasomata, a family which is so characteristic of all the countries surrounding the Mediterranean. On dead corpses of donkeys, goats, &c., which the inhabitants leave on the spot where they die, one might find a *Silpha*, on sunny places fine species of *Cicindela*, and on the leaves of the tamarisks Coccinellidæ are not uncommon. Hemiptera were scarce, only one *Cimex* having been found; and so were Lepidoptera, both perhaps partly because the season was not propitious. Myriapoda were represented by a large *Scolopendra* and a *Geophilus*.

The Araneidæ are comparatively very abundant (no Scorpions found), a magnificent large yellow species of *Epeïra* extending its net between the branches of the tamarisks, and a yellow crab spider, as well as a *Salticus*, living commonly on the ground. Under small labiaceous plants a very fine green spider, not unlike a *Theridium*, occurs, numerous specimens of which will be found in our bottle. It makes an irregular web in the middle of the shrub, and comes out only when you lift the plant and shake it, then running away with the utmost speed.

On the beach two Crustacea are to be found; both are rather interesting. One of them is a *Remipes*, which may be seen half-burrowed in the sand, only its head sticking out and watching for its prey. The boys in the place catch it by throwing a piece of meat on the ground immediately after the waves have gone back, when the *Remipes* will come out and try to seize it. The other crustacean, which makes holes on the beach in the dry sand, is *Ocypoda ippeus*, known from Egypt, Syria, and these islands. It is one of the species which have the eyes on the sides of the stalk, which itself surpasses the eye in length, and is terminated by a tuft of hairs. On the rocks of the beach a *Grapsus* is very common, hiding itself everywhere in the holes between them; and at low water *Palæmon*, *Pagurus*, *Eunice*, *Aplysia*, and many shells were easily picked up. A large *Calappa* was caught in the trammel, together with a *Scarus*, *Dactylopterus*, and a fine specimen of *Zygæna malleus*, caught by Mr. Balfour.

In St. Iago I frequently visited the palm-groves close to the town, where I caught many insects and watched the land-crabs (Gecarcinidæ), which had undermined the whole of the place with large holes. In the evening one of them, a *Cardisoma*, was caught by the seeking party, and on closer inspection was found to have eggs and young ones just come out of them under its abdomen. This was of considerable interest, because we knew that the West-Indian *Gecarcinus* undergoes no metamorphosis, but that another species was said to do so by V. Thompson, who had seen dead Zoëas in its eggs. This *Zoëa*, however, had not been drawn (as far as could be made out), and the whole thing had been doubted, according to statements given by Fritz Müller. We were therefore very much satisfied not only by ascertaining that the young ones also of this species were Zoëas, but by being able to make an accurate sketch of those which had already left the egg. No doubt these would have left the mother on her nocturnal excursions to the sea, and undergone there the ordinary metamorphoses.

On the 28th of August we landed on the rocks of St. Paul, where nobody is known to have made collections since Darwin's well-known visit to the place. On the barren rocks there are hardly any insects to be found, and nearly all there is of animal life is more or less dependent on the bodies or nests of the two birds which cover these rocks, *Anous stolidus* and *Sula fusca*. These nests were carefully searched not only in the island, but also afterwards in the laboratory, where I had taken a box full of them in order to secure as many specimens of the insects as possible. The following animals were thus procured:—(1) a *Chelifer*, several specimens from the nest of *Anous stolidus* (the best places to find our European *Chelifer* are the nests of *Hirundo urbica*); (2) three species of spiders; (3) a tick, very common; (4) a small dipter; (5) pupæ of *Olfersia*, the pupiparous parasitical fly; (6) a microlepidopter; (7) a lepidopterous larva.

Darwin does not mention the *Chelifer* in his list, but has, on the other hand, a *Quedius* (beetle) and a wood-louse, which I have not been able to find.

All over the island a large *Grapsus* is very common, preying on the eggs and young ones of the birds. In pools large black *Actiniæ* may be seen, and many small fish which come and go by high water. In the lobster-pots we got several small specimens of a *Palinurus*.

On the main island of Fernando Noronha we only took a short walk, as we then thought, in order to look over the place and see where collecting might be most profitably done, but, as it proved afterwards, never to return. Large quantities of pigeons were seen in the woods, lizards in quantities everywhere (*Euprepes punctatus*), and under the stones a small *Gryllus* was to be seen by thousands. Besides these I only noticed a centipede.

On the second day we paid, with Captain Nares, a visit to Mount St. Michael, Rat Island, and Platform Island. The rather steep rocks of the former are the resting- and breeding-places of *Anous stolidus*, *Sula* *fusca*, *Tachypterus aquila*, and *Phœnicurus œthereus*, great numbers of which may be seen flying about.

Among the creepers which cover the stony ground I found several green *Cicadæ*, a *Locusta*, and very large yellow spiders, which are also very common on the mainland.

On the beach I found a large *Nerita* and the *Grapsus* (c. f. *strigosus*) from the rocks of St. Paul.

Rat Island.—Among the white *Convolvulus* we saw and caught some specimens of a *Polyommatus*, the only butterfly which was seen, with the exception of a few small Microlepidoptera. Pigeons are common here.

Platform Island.—The rocks on the beach are covered with a small *Mytilus*; and among these mussels specimens of a *Patella* were found.

In each island our stay was extremely short. Every thing, however, that came in our way was eagerly collected; nevertheless the result will not give an idea of the Fernando fauna, as no collecting could be done on the mainland.

15*th October*, 1873.—Landed on the lower ground of Tristan d'Acunha, and remained six hours on shore collecting every thing I could find. On the beach I saw underneath the seaweeds many Diptera, all of one species, and under the stones *Oniscus*, *Iulus*, and a *Lumbricus*. Besides these there was a small *Scolopendra*, but scarcer than the former. Here I also found a small *Limax* in great quantities, which was just laying eggs (the corresponding species in northern Europe does so in April). In a pool near the beach, the water of which was brackish, I saw a small whitish Oligochæt.

Of land-mollusca I found a small species resembling in shape our genus *Zonites*, and secured a good many specimens of them.

Several small spiders were gathered among the grasses and under stones.

Proceeding then towards the settlement, I examined in many places the dung of cows and sheep, but could find no trace of the *Aphodii*, *Geotrupes*, and other beetles which, with us, are invariably to be found underneath it. All I got was a small *Staphylinus*. Going into the houses, and asking for any objects of natural history which might have been collected and kept by the inhabitants, I got quantities of a *Buccinum* found on the beach, with *Patella*, *Chiton*, and others, also a dried sea-urchin and a living *Procellaria glacialoides*. This bird, which is common on the antarctic coast of South America, seems to be unknown to the fishermen of Tristan. Of course we also made inquiries about the butterflies, none of which had been seen flying about, asking especially if they had not a dried specimen of them in a book or on a pin. They, however, had none, said it was not the proper time of the year for it, and described it minutely—very likely *Vanessa urticæ*, a species common all over the world.

There are no wild mammals on the island except rats and mice, no reptiles, and no amphibia. Of the three species of land-birds we only saw the Thrush (*Nesocichla eremita*, Gould), which seems to be common and very tame into all the three islands of the group. The yellow *Emberiza brasiliensis*, so common in the other islands, seems to have become extinct in Tristan Island, or never to have been there; for the two destitute Germans on Inaccessible Island told me that the Tristan people had tried to introduce the bird into their island, but they did not know whether they had succeeded. *Gallinula nesiotis* is still to be found high up in the hills. Several specimens of it had been sent to Capetown, and one of them had been sold last year to a merchant-ship.

16*th October*.—Landed in the morning on the lower ground of Inaccessible Island, and collected a good deal among the *Phylica*-shrubberies on the small hill. Here we got several *Curculiones*, an Hemipter, a moth, and many caterpillars, besides the insects already mentioned from Tristan Island. The two Germans gave me their popular names for the butterflies, of which they distinguish two species (a "Fuchs" and a "Perlmutterfalter"—*Vanessa* and *Argynnis*).

In the pond at the foot of the waterfall we got several specimens of an *Hydrobius*.

The *Nesocichla* and *Emberiza* were very common. Of *Nesiotis*, which the Germans declared to be a smaller bird than the Tristan one (?), some pairs had been seen previously on the lower ground, but they were commoner on the top of the hills.

17*th October*.—Collected some beetles and other animals among the *Phylica* trees and on the corpses of dead puffins, as well as in the nests of the albatrosses. *Nesocichla* and *Emberiza* were very common; no *Nesiotis* was seen.

List of the land-animals collected in the Tristan d'Acunha group.

AVES.—1. *Nesocichla eremita*, all three islands; 2. *Emberiza brasiliensis*, Inaccessible and Nightingale Islands.

MOLLUSCA.—1. C.f. *Zonites*; 2. *Pupa*; 3. *Limax*.

ARACHNIDA.—1. *Drassus*, sp.?, common in Tristan Island, rarer in Inaccessible Island, not seen in Nightingale Island; 2. Several other small spiders; 3. A tick, parasitic on *Diomeda chlororhynchus*.

MYRIAPODA.—1. *Iulus*, common everywhere; 2. *Scolopendra*, common everywhere.

COLEOPTERA.—1. *Curculio*, three to four species in all the islands; 2. *Staphylinus*, everywhere; 3. Small black Chrysomelid; 4. *Hydrobius*, Inaccessible Island.

HEMIPTERA.—1. Cimicid, Inaccessible Island; 2. Small *Cicada*, Nightingale Island.

LEPIDOPTERA.—1. *Noctua*, Nightingale Island; 2. Microlepidopter, from Inaccessible Island; 3. Caterpillars, Inaccessible Island.

DIPTERA.—1. Muscid, everywhere; 2. *Pulex*, parasitic in the nests of *Diomedea* and *Eudyptes*.

PODURIDÆ.—*Thysanura*, on a dead puffin.

CRUSTACEA.—1. *Oniscus*, everywhere under stones; 2. *Gammarus*, everywhere under stones.

OLIGOCHÆTÆ.—*Lumbricus*, everywhere under stones.

V. "Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Crustacea observed during the cruise of H.M.S. 'Challenger' in the Southern Sea." By the late Dr. RUDOLF VON WILLEMÖES-SUHM, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876. Read March 16.

In the following paper it is intended to give a short account of the Crustacea found at the bottom as well as on the surface of the sea during the antarctic cruise of H.M.S. 'Challenger.' Our expedition, as is probably well-known to most readers, left the Cape on December 17, proceeded towards the Prince-Edward Islands, and landed on one of them. Between these islands and the Crozets, on which landing was impossible, we had several successful deep-sea dredgings. From the Crozets we sailed to Kerguelen, where we stayed nearly a month, and where a great deal of shallow-water dredging was done. Proceeding from this large island to the south, we penetrated beyond the antarctic circle, and had four successful deep-sea dredgings near the ice-barrier. On our way to Australia we were able to trawl five times.

The surface animals were generally collected by the towing-net at every station by lowering the net to a depth of 50–100 fathoms, where, as experience has shown us, nearly the same quantity of animals are found during the day which at night are to be got from the very surface. In fine nights, when the ship was gliding very slowly through the water, the net was of course always put out, and its contents were carefully preserved; but during our antarctic cruise such nights were rare, so that in most cases we had to lower the net in the daytime, during the manipulations of dredging and sounding.

In shallow water near the shores of the antarctic islands we found scarcely any of the higher Crustacea. Only on the north coast of Marion Island (Prince-Edward group, the northernmost of the islands which we visited) a small Caridid shrimp was got in considerable numbers. Besides there was a *Serolis*, different from the only species which we had met with (in 700 fathoms off the coast of Brazil). On the south coast of Prince-Edward Island there were no Decapods at all in a similar depth, only *Serolis* came up in the dredge. Near the same place, however, we got a successful dredging from 310 fathoms, showing that the conditions, whatever they may be, which do not allow the higher Crustacea to live in shallow water near the antarctic islands (a fact which will be shown to be also the case near Kerguelen and Heard Islands), do not apply to greater depths; for now we found plenty of higher Crustacea, fine Caridid decapods, Galatheas, and large spiny brachyurous crabs, allied to *Pisa* and *Maia*, of the finest red colour. This was the only time we got near the islands a dredge in such an intermediate depth as 310 fathoms.

Halfway between Prince-Edward Islands and the Crozets we had two trawlings in greater depths, both successful and very important, as they showed clearly that also in these southern regions of the Indian Ocean several of the animals are to be found which inhabit the deep sea of the Atlantic. *Euplectella*, *Hyalonema*, *Umbellularia*, *Brisinga*, *Pourtalesia*, as well as *Macrurus* and *Halosaurus* were all well-known forms to us, and in most cases, I should think, the same species which we have found all over the Atlantic. The Crustacea were represented by several *Scalpella*, which were attached to Bryozoa by the same bluish *Serolis* which we got the first time on the coast of Brazil in 700 fathoms. An *Arcturus* was rather common, and so was an Isopod, which is very characteristic for the antarctic deep sea, but which nearly always comes up completely spoiled, as it loses all its antennæ and legs, evidently breaking like glass. We succeeded only once in getting a specimen, 24 millims. long, in which the second antennæ and the legs were preserved; and this one shows that it has a very long flagellum of the second antenna and the third and fourth pereiopods elongated and exceedingly thin. Its subsequent pereiopods are foliaceous swimmerettes, and its abdomen consists only of one segment. All this, besides its blindness, shows that it is a member of the family Munopsidæ, established by Sars, who has described several genera. Besides this larger species we found a smaller one in the antarctic deep sea which probably belongs to the same genus, but is rarer and equally very liable to lose all its appendages. Another Munopsid, which, however, may belong to a different genus, was found formerly by us in deep water (2175 fathoms) in the Atlantic, between Bermudas and the Azores, in lat. 38° 3′, long. 39° 13′ W. It is very large, 40 millims. long, and perfectly transparent and soft, so that it collapses as soon as taken out of the water. Its first antenna is of moderate size, the second is broken. The first pereiopod is a prehensile organ; the three subsequent ones are broken. The last three feet are terminated by exceedingly large foliaceous joints, and the abdomen consists of one single segment. The large posterior pereiopods make this strange animal look still stranger; but it is in every respect a normal member of the family Munopsidæ. I shall describe all these species when I come home, and shall be able to compare them with Sars's drawings.

The deep-sea dredging between Prince-Edward Islands and the Crozets brought us also an immense ostracod, gigantic if compared to those forms which are known to us as common inhabitants of the fresh and salt water. Its soft sculptured shell has a length of 25 millims. and a height of 16 millims. The small cover formed by two excisions of the shell before the head has by itself the considerable length of 3 millims. I think this is the largest of all Ostracods known, only equalled in size by a Silurian form found in the island of Gothland, and described as *Cytherina baltica.* According to Quenstedt there seems to have been some doubt whether this is really an Ostracod, as it is ten times larger than any living form hitherto known. This deep-sea form shows that there is no reason for that; but unfortunately it does not allow me to decide to what family it belongs, for nothing is left of the animal inside the shell but the head with the eyes, the two antennæ, and what I consider to be a palpus mandibularis. The shell is rather soft and flexible, divided by five lines, originating from a central point in its anterior part, into as many fields, the largest of which on the posterior and inferior side is sculptured. The eyes are very large, pedunculated, and consequently movable. So far the description of the animal does not prevent its being put into the family Cypridinidæ; but the antennæ seem to me very different from those known in that group; for here the funiculus antennæ primæ has got four joints, the last of which has on the upperside an accessory prolongation, which resembles somewhat the scale on the lower antenna of higher Decapoda, but seems not to be in articulation with the funiculus. The flagellum seems to consist of twelve joints with a tuft of hair at the top. But about this number I am not quite sure, as I could not count them in a satisfactory way without spoiling the precious unicum. The lower antenna has, as far as I could make out, only a single flagellum (whereas the Cypridinidæ have got two), consisting probably of nine joints. The palpus mandibulæ, finally, resembles in its shape very much the one which is found among the Decapods, consisting of two joints, the last of which is covered with hairs on its inner side.

Probably this new and gigantic Ostracod belongs to one of the established families, a fact which, I hope, will be elucidated by further discoveries on our future cruise in the southern hemisphere.

This is not the only example, however, of gigantic forms in the deep sea, for the same trawlings brought up two specimens (from 1375 and 1600 fathoms) of a Gammarid Amphipod the larger of which has a length of 60 millims. and a height of 35 millims. Though we now know that certain Hyperids (*Cystisoma Neptunus*, both sexes of which we found in the Atlantic, and described in the Phil. Trans. 1873; see also Trans. Linn. Soc. 1875, 2nd ed. Zool. i. p. 24) attain the considerable length of more than 4 inches, these transparent and elongated animals do not make such an impression as the Gammarids, which are besides in no way peculiar, being perfectly normal, and approaching perhaps most the genus *Typhimedia*. I shall therefore give later a more accurate description of them, and *here only direct attention to the fact that in the deep sea, as well as in the sedimentary strata, animals are found which, compared with their relations living now-a-days and in shallow water, are of a very considerable size*; and I may perhaps best in this place add that in this dredging of 1375 fathoms a Nymphoid (Pycnogonid) was got measuring nearly *two feet across the legs*.

The Schizopods appear to gain most by the deep-sea investigations; for strange forms have been discovered by us as in the Atlantic, and strange forms continue to come up as we go on with the researches in the other oceans. The *Chalaraspis unguifer*, which constitutes a new family (as has been shown in my paper on the Atlantic Crustacea) allied to the Lophogastridæ, and characterized by the presence of all the pereiopods, the looseness of its dorsal shield, the absence of accessory eyes, &c., is one of the characteristic members also of the antarctic deep-sea fauna. It was got in these dredgings, as well as in those on our way from the Antarctic to Australia, when another new genus of this family came up, of which I shall speak afterwards. In these trawlings near the Crozets we got another Schizopod, a new species of my genus *Petalophthalmus*, first found in the tropical deep sea of the Atlantic. It is a form differing from the Mysidæ by the looseness of its dorsal shield, by large plate-like duplicatures of the chitinous substance in the place where we are accustomed to find the eyes, and by the presence of breeding-lamellæ at the base of all the pereiopods. I must refer for the details to my previous paper, where I have discussed its zoological position and its nearest relations, and may here only repeat that the male of the Atlantic species *P. armiger*, v. W. S., differed very much from the female and showed characters hitherto never found in a Schizopod. Its first antenna, palpi mandibulares, maxillipeds, and first gnathopods are transformed into very powerful prehensile organs. In this species, which is much larger than the Atlantic one (length of the female 62, of the male 55 millims.), nothing of the kind exists. The male is only a little smaller than the female, has of course no breeding-lamellæ, and is only distinguished by the presence of two small recurved tubes, situated behind the last pair of pereiopods, and having evidently the function of copulative organs. Besides the pleopods are larger than in the female, and have, as is the case in many Mysids, got two rami. I shall call this species *Petalophthalmus inermis*, as the chief difference from *P. armiger* consists in the resemblance of the male to the female and in its size. The parts of the mouth as well as the other appendages are very much alike in both species. Drawings of most of them have been made, and will be published on a later occasion. As we got many specimens of this larger species, I examined the curious petaliform organ which morphologically represents the eye, and found that it consists of nothing but a double chitinous layer, which contains a small quantity of muscular tissue.

The same petaliform organs, but on much shorter stalks and of different size, are met with in another animal which came up in these dredgings, and which belongs to the proper Mysids, as its carapax is not loose, as in *Petalophthalmus*, but adheres to the segments of the pereion, as in ordinary shallow-water Mysids. It has a length of 35 millims., and, being a male, is distinguished by two, small, tube-like copulative organs at the base of the last pair of pereiopods. A form of the same genus was afterwards found in shallower water near Kerguelen, the females of which had got young ones in their pouches, showing that they undergo the same metamorphosis as *Mysis* does. They are in consequence closely allied to this genus, and have nothing to do with *Petalophthalmus*, though the eyes have undergone the same retrogressive metamorphosis as in this genus.

In these dredgings we caught several of the higher Decapods, Galatheas, several specimens of *Pugurus*, and Caridid as well as Peneid shrimps. One of the Caridids was important to us, as it was the same species which we had formerly got in quantities in deep water off the coast of Brazil between Pernambuco and Bahia. It has a very solid and spiny carapax and large eyes. From a morphological point of view all these crabs and shrimps have, however, scarcely any interest.

When cruising near the Crozets we dredged in a depth of 210 fathoms, where only a *Serolis* was got, and again in 550 fathoms, where no Crustacea came up at all.

In Kerguelen Island, where we stayed nearly a month, much shallow-water dredging took place in the different harbours, most of which was done by Prof. Wyville Thomson himself, while I was on shore collecting the land animals of the place. There is no *Gammarus* with terrestrial habits nor any Oniscas to be found in these barren islands, animals which still exist on the Tristan d'Acunha Islands. In the pools on shore, however, a small brachyurous crab was found, which was never got by the dredge not even in the shallowest water. Also in the pools it is by no means common, so that I only got three specimens. One of these, a female, had empty eggshells attached to its pleopoda; and I think that a small *Zoëa*, the only larva of higher Crustacea which I was able to get on the surface, belongs to this species; for *all the dredgings down to a hundred fathoms near Kerguelen Land never yielded any of the Decapod Crustacea except the small Mysid which has been already mentioned.*

The shallow-water fauna near Kerguelen may be divided into two zones—the one going from a few fathoms down to forty, and characterized by small silicisponges, a *Spatangus*, *Cribrella*, and especially by *Serolis*; and the second from 40–120 fathoms, inhabited by large silicisponges (*Rossella antarctica*, Carter), a large red Euryal, *Comatula*, another *Serolis*, by *Cuma*, *Tanais*, and *Anceus*. These two zones of course are not strictly separate, as many of their inhabitants go from one into the other; but I do not think, for example, that *Spatangus* will be found to be anywhere plentiful beyond 50 fathoms; nor do I think that *Rossella* will be found at all in a depth of 25 fathoms.

The Crustacea inhabiting the shallower water are several species of *Serolis*, *Sphæroma*, *Arcturus*, some Gammarids, several species of *Caprella*, one of which has a very slender and long manus, and some Pycnogonids. There is scarcely any thing interesting to be found in that zone. In the second zone of deeper water (though not deep-sea fauna, which we scarcely ever have found in less than 500 fathoms) we had a richer harvest; *Tanais* and *Praniza*, very curious amphipods, Mysids and *Nebalia* are the inhabitants, about which I shall now say a few words.

A *Tanais* having a length of about 17 millims. is very common, and though not deviating by any means from the typical species of the genus, it has a peculiarity connected with its propagation; for the females, instead of having breeding-lamellæ, as the other species of the genus have, carry their eggs, like Copepods, in small cutaneous sacs attached to the genital opening at the base of the fifth pair of pereiopods. These sacs extend as the development goes on, and attain a diameter of 3–4 millims. Professor Wyville Thomson having discovered among the echinoderms of Kerguelen Land many forms which do not undergo any metamorphosis, but develop in pouches of their parents, this peculiarity in *Tanais* deserves to be noted, not exactly as comparable to those facts, but as an anomaly in the group to which the animal belongs.

Less common than this *Tanais* was an animal which very closely resembles the European *Anceus maxillaris* (*Praniza*, Leach), of which I got several males and ovigerous females.

A larger species of *Serolis*, which is the predominant and most characteristic form of all the Crustacea in the shallow water of the Antarctic islands, was also to be found in this second zone. With it an Amphipod occurred, a Gammarid, distinguished by a bright *red frontal prolongation* of the head and having no eyes. These I first thought might be discovered in some form or other in the red proboscis; but my expectations were not justified by the results of the dissection. The organ is divided by a line along its top into a right and a left portion. The chitinous layer has got no facettes, and the whole organ is filled by a finely granulated red pigment. What its function may be I cannot say, having never met with any thing like it.

The *Nebalia* was very rare. Though I sifted the mud for a long time, and was most anxious to find more specimens of it, I only succeeded in getting two females, which differ from *N. Geoffroyi* only in having the borders of the abdominal segment somewhat more sharply denticulated. Until, however, the male is known I do not think it right to declare it to be the same species.

Besides a small *Cuma*, which was very common, we found in the deeper zone outside Christmas Harbour the only decapod which was brought up by the dredge during the whole time of our stay in Kerguelen, where dredging has been effected at least in seven different places. This was a small Mysid with petaliform plates instead of eyes, allied to the larger species which was brought up from the deep sea. It has a length of 12 millims., and was not rare, as numerous males and females with young ones in their pouch were found in the mud. The females have got (as all Mysids have) two pairs of large breeding-lamellæ, which form a pouch for the reception of the young.

Possibly this Mysid genus is already described by Sars, who has established several genera, the descriptions of which are unfortunately not on board.

These are the Crustacea of the shallow water near Kerguelen — all belonging to the lower divisions, whose breeding-lamellæ form a pouch for the reception of the young. The only Decapod among them is (which is very remarkable) an animal in which the pouch is not wanting; so that it seems that *in the shallow water near the Antarctic Islands higher Crustacea have not been able to find those conditions which are necessary for their development.* The Echinoderms which have found the same difficulties have partly overcome them, by being represented here, especially by forms which have no metamorphosis, and in which the young ones find protection with the mother. The Crustacea (with only one exception, the Brachyurous crab in the pools) which develop with free-living larval stages have not been able to resist influences which seem to be especially hostile to the larval stages of these groups. In the deep sea, however, as well as on the surface of the ocean, we find higher and lower Crustacea distributed in the same way as they are in other regions of our globe.

Between Kerguelen and Heard Island we dredged in 150 fathoms, but got only a *Scalpellum*, an *Arcturus*, and a spiny Amphipod, which is the corresponding form to the *Gammarus loricatus* of the north. Near Heard Island, in 75 fathoms, we found the same animal and a *Sphæroma*, but no other crustacean at all.

Near the ice-barrier in the South we had three deep-sea hauls in 1260, 1675, and 1975 fathoms, but got only very few Crustacea, a spiny Isopod, the Munopsid which has been mentioned before, and a large *Serolis* (in 1975 fathoms), which has been figured by Mr. Wild, and which we propose to call *T. Bromleyana*, in honour of Mr. Bromley, Lieutenant in H.M.S. 'Challenger,' who has been many a time in charge of the deep-sea dredgings. The males of this species have a length of 54, the females of 46 millims.; and both sexes are distinguished by a fine blue colour, with a red spot extending over the midst of the body and the eyes. The lateral segments of the pereion are terminated in long spines, which are directed backwards, and attain in the male the length of 59 millims. and 43 millims. in the female.

On our way from the ice-barrier to Melbourne four successful hauls were got in depths of 1950, 1800, 2150, and 2600 fathoms. In the second of these hauls we found a rhizocephalous cirriped in the open breeding-pouch of a very large *Hymenaster*, which is about to be described by Professor Wyville Thomson. Such crustaceans have, however, as far as I can see, never been described from an echinoderm; and I am not quite sure whether the specimen in question had not been detached from one of the shrimps which came up at the same time and tumbled into the open pouch of the *Hymenaster*. Another Cirriped, a *Scalpellum*, was caught in the last dredging (2600 fathoms), showing once more that Cirripeds are among those Arthropods which may be met with in very great depths. Of Isopods there were specimens of the described Munopsid, and fragments of another hitherto unknown member of this tribe.

The Schizopods yielded again several very interesting forms. *Petalophthalmus inermis* came up from 1950 fathoms, and from the same place we got the posterior part of a cast *Gnathophausia* skin. This genus, three species of which have been described by me from the depths of the Atlantic, is allied to *Lophogaster*, but distinguished by its carapace being not attached to the five posterior segments of the pereion, and by accessory eyes on the second maxilla. It is difficult to tell from this fragment whether it belongs to one of the described species: in size it seems to me to have been intermediate between *G. gigas* and *G. zoëa*. The Euphausiidæ are also represented by a very interesting new form, a large species of *Thysanopoda* (from 1800 fathoms), a genus which has hitherto not been found in deep water. It has a length of 50 millims., and is, like the deep-sea *Euphausia* which I have described in my preceding paper, perfectly untransparent. I am not able to say how many pairs of accessory eyes there are in this species, but I think that they exist, and that black spots between the first pleopods may turn out to be such organs of sense.

Of *Chalaraspis* there was a specimen of the species which I have mentioned already (*C. unguifer*), and another very remarkable form which I shall call *C. alata*. In this one the large carapace is very thin and soft, perfectly loose, and covers three of the abdominal segments. The last legs are not elongated like in *C. unguifer*, but somewhat shorter; the first of them somewhat enlarged and recurved in its first joints.

Among the higher Decapods there were two species of *Galathea* and some Peneid and Caridid shrimps, which are not particularly interesting.

VI. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work (Chemical and Geological) done on board H.M.S. 'Challenger.' By J. Y. Buchanan, Chemist and Physicist to the Expedition. Communicated by Professor Wyville Thomson, F.R.S. Received March 7, 1876. Read March 16.

The following Preliminary Report on my work on board the 'Challenger' during the last three years has been drawn up in compliance with a request on the part of Professor Wyville Thomson, which was communicated to me on the 23rd June, 1875. As my time at sea is fully occupied with the daily laboratory work, I was obliged to postpone preparation of the report until our arrival at Valparaiso, where the whole of my time was devoted to it. Three weeks, however, is too short a time to prepare even a preliminary report with satisfaction, and there are doubtless many things in the present one for which I must crave indulgence. In venturing to publish the few geological notes which I have embodied, I feel that a special apology is required, as my knowledge of rocks is, at best, but superficial. I was emboldened to do so, however, by considering that the islands to which the notes refer are principally such as are but seldom visited by any one, and that, as it was my good fortune to be able to visit them, it was right that I should make what observations I could and record them, in case amongst them there might be some which would be of value to the geologist.

Observations on the Specific Gravity of Sea-water.

As the value of these results depends to a great extent on the nature of the means taken to collect the water, and on the delicacy of the instrument used for determining its specific gravity, I shall shortly describe them both.

The samples of water are collected either in an ordinary canvas bucket, or in one of two kinds of metal "water-bottle," according as it is to be taken from the surface or from depths below it. The use of the ordinary hand-bucket needs no explanation. When water is to be obtained from the bottom, the "slip" water-bottle is used. This instrument is a Swedish invention, improved by Dr. Meyer, of Kiel, who without doubt has described it, and by Messrs. Milne, of Edinburgh, who furnished those on board the 'Challenger.'

Water from intermediate depths is obtained in a much lighter instrument, which, with a drawing and the method of using it, is fully described in a paper presented to the Royal Society in the early part of 1875, of which an abstract has been published in the 'Proceedings,' No. 160. It consists of a metal cylinder furnished with stopcocks at both ends. The levers by which these stopcocks are turned are connected by a straight rod, so that they are simultaneously either open or shut, or at least at the same phase of being open or shut. When water is to be collected by its means, the stopcocks are opened and the instrument sunk to the required depth, having been previously securely fastened to a sounding-line. The operation of sinking must be carried on without a check, owing to the peculiarity of the closing-apparatus. When the required depth has been reached, the line is checked, hauled in a few fathoms, let go again, and finally brought to the surface by means of a donkey-engine. The rod connecting the stopcocks is furnished with a metal plate, which, during the descent, is retained in a vertical position by the passage of the water on both sides of it. When, however, the direction of motion is reversed, the plate falls down into a horizontal position, when, by its passage through the water, it exercises such a downward pressure on the rod that the stopcocks are closed. Arrived at the surface, it contains the water which it had enclosed at the depth in question. A small safety-valve allows of the escape of the surplus water, which, owing to the greater density of the water below the surface, it has enclosed in excess of what it can hold at atmospheric temperature and pressure. The apertures of the stopcocks being necessarily smaller than the diameter of the cylinder, the efficiency of the instrument in really changing the water as it descends was tested before leaving England in a freshwater lake, the water with which it was filled at the surface containing some yellow prussiate of potash. It was found that the water fetched, under these circumstances, from depths over 1½ fathom was unacted upon by solution of perchloride of iron. The rate, therefore, of change of water is satisfactory, as we can be certain of obtaining an average sample of the last two fathoms passed through by the instrument.

Representing the specific gravity of distilled water at 4° C. by 100,000, I found that of ocean water at 15°·56 C. to vary between the extremes of 102780 and 102400; so that, to be of any value at all, the possible error in the results must not exceed 10. The hydrometer used for these observations is fully described in the paper above referred to. Its description is briefly as follows:—

The stem, which carries a millimetre-scale 10 centimetres long, has an outside diameter of about 3 millimetres, the external volume of the divided portion being 0·8607 cubic centimetre; the mean volume of the body is 160·15 cubic centimetres, and the weight of the glass instrument is 160·0405 grammes. With this volume and weight it floats in distilled water of 16° C., at about the lowest division (100) of the scale. In order to make it serviceable for heavier waters, a small brass table is made to rest on the top of the stem, of such a weight that it depresses the instrument in distilled water of 16° C. to about the topmost division (0) of the scale. By means of a series of six weights, multiples by 1, 2, 3, 4, 5, and 6 of the weight of the table, specific gravities between

1·00000 and 1·03400 can be observed. It is not necessary that these weights should be accurate multiples of the weight of the table; it is sufficient if they approach it within a centigramme, and their actual weight be known with accuracy. The weights of the table and weights in actual use are:—

Weight of table		0·8360	gramme.
Weight of weight No.	I.	0·8560	„
„ „	II.	1·6010	„
„ „	III.	2·4225	grammes.
„ „	IV.	3·1245	„
„ „	V.	4·0710	„
„ „	VI.	4·8245	„

For oceanic waters the hydrometer is always used with the table and either No. IV. or No. V. weight.

When the mechanical part of the construction of the instrument was finished, with the exception of the closing of the top of the stem (which instead was widened into a funnel-shape large enough to receive the ordinary decigramme weights), the calibration of the stem was effected by loading the stem with successive weights, and observing the consequent depressions in distilled water of known temperature. This done, the top was sealed up and the instrument carefully weighed. The expansion of the body with temperature was determined in a similar manner by reading the instrument in distilled water of various temperatures. The coefficient of expansion of the glass was then found to be 0·000029 per degree Centigrade.

For using this instrument at sea about 900 cub. centimetres of sea-water are taken, and the containing cylinder placed on a swinging table in a position as near the centre of the ship as possible. The observation with the hydrometer, loaded with the necessary table and weight, is then effected in the ordinary way, the accuracy of the readings being but little affected by rolling; pitching, however, is found to have a distinctly disturbing effect; and when it is in any way violent, it is advisable to store the specimen of water till the weather improves.

The temperature of the water at the time of observation is determined by one of Geissler's "normal" or standard thermometers, graduated into tenths of a degree Centigrade; and it is essential for the accuracy of the results that the water, during the observation of the hydrometer, should be sensibly at the same temperature as the atmosphere, otherwise the changing temperature of the water makes the readings of both the hydrometer and the thermometer uncertain. At low temperatures (below 10° or 12° C.) a tenth of a degree makes no sensible difference in the resulting specific gravity; but at the high temperatures always found at the surface of tropical seas, rising sometimes to 30° C., the same difference of temperature may make a difference of 3 to 4 in the resulting specific gravity.

Having obtained the specific gravity of the water in question at a temperature which depends upon that of the air at the time, it is necessary, in order that the results may be comparable, to reduce them to their values at one common temperature. For this purpose a knowledge of the law of expansion of sea-water with temperature is necessary. This had been determined with sufficient accuracy for low temperatures by Despretz and others; but as the temperatures at which specific-gravity observations are usually made are comparatively high, their results were of but little use, directed as they were chiefly to the determination of the freezing and maximum-density points. When the late Captain Maury was developing his theory of oceanic circulation, owing to difference of density of the water in its different parts, he found the want of information on this important subject. At his request the late Professor Hubbard, of the National Observatory, U.S., instituted a series of experiments, from which he was enabled to lay down a curve of the volumes of sea-water at all temperatures from considerably below the freezing-point to much above what obtains even in the hottest seas. The results are published in Maury's 'Sailing Directions,' 1858, vol. i. p. 237, and have evidently been carried out with great care. The composition of different oceanic waters varies, even in extreme cases, within such close limits, that the law of thermal expansion is sensibly the same for all of them; of this Hubbard's experiments afford satisfactory proof. In the Table which gives the results of all his experiments he takes the volume of water at 60° F. as his unit. In order to avoid much useless calculation, I have been in the habit of reducing my results to the same temperature (15°·56 C.), while, for a like reason, I have retained the specific gravity of distilled water at 4° C. as the unit. The choice of a common temperature to which the results should be reduced, and of a unit of specific gravities, is a purely conventional matter; and in choosing the above-mentioned ones, in the first instance, I was moved solely by a desire to save calculation. For every water, however, there is one temperature to which it would be *natural* to reduce its specific gravity, namely, the temperature which the water had when in its place in the ocean; and in this sense all my results during the cruise have been reduced. Hubbard's Table of the change of volume of a mass of sea-water with change of temperature enables us very easily to reduce any observed specific gravity from the temperature of observation to any other temperature, say 15°·56 C. In the paper it is transcribed from the 'Sailing Directions.'

In the following Table the volumes for every Centigrade degree from −1° C. to +30° C. are given:—

Temp. ° C.	Volume.	Temp. ° C.	Volume.	Temp. ° C.	Volume.	Temp. ° C.	Volume.
−1	0·99792	+7	0·99853	+15	0·99987	+23	1·00194
0	795	8	866	16	1·00010	24	224
+1	799	9	878	17	034	25	256
2	804	10	893	18	059	26	288
3	812	11	910	19	086	27	320
4	820	12	927	20	111	28	352
5	830	13	947	21	137	29	385
6	840	14	967	22	164	30	420

By means of the results given in this Table a chart of isothermals was constructed, giving by inspection, as soon as the specific gravity at any one temperature is known, its reduced values at any other. In this way the specific gravity of every water has been reduced to its value at 15°·56 C. and at the temperature which it possessed when in its place in the sea.

The results obtained since leaving Teneriffe on 15th February, 1873, are given in a series of Tables, in which those relating to surface-water are collected together and grouped in sections, as Teneriffe to St. Thomas's, St. Thomas's *viâ* Halifax to Bermuda, and so on. Those relating to bottom-water are collected in larger groups—the first containing all those observed in the Atlantic, the second those in the Southern, the third those on the western side of the Pacific Ocean, and the fourth those observed between Japan and Valparaiso. Where series of observations on waters from intermediate depths have been obtained, each series is given by itself. By far the greater number of the observations relate to surface-water, the specific gravity of which was, as a rule, taken once a day when at sea, the temperature of the water being at the same time observed with the standard thermometer above mentioned.

With a single exception, off the coast of Brazil, the densest water which we have met with in the ocean was found on the section from Teneriffe to St. Thomas's in the heart of the north-east trade-wind territory, where, from the strength and dryness of the wind, the amount of evaporation must be very large. Round about the Canary Islands the mean specific gravity was found to be 1·02730; to the westward it rises steadily until in longitude 28° W. it has reached 1·02762. Between longitude 28° W. and 54° W. the mean specific gravity is 1·02773, the maximum being 1·02781. On approaching the West Indies it rapidly falls off to an average of 1·02719 in the neighbourhood of St. Thomas's; and if we take into account all the observations made on the western side of the Atlantic, from St. Thomas's northward to the edge of the cold water which separates the Gulf-stream from the coast of America, we obtain the same average, 1·02719. Between Bermuda and the Azores an almost perfectly uniform specific gravity was observed, the mean being 1·02713, and the extremes 1·02694 and 1·02727. As Madeira is approached the specific gravity rises until it reaches 1·02746 close to the island itself. The mean specific gravity on the eastern side of the North Atlantic, between the latitude of St. Thomas's and that of the Azores, is 1·02727, or slightly higher than that of the water on the western side.

After leaving the Cape-Verd Islands, the ship's course lay almost parallel to the African coast, and at an average distance of about 200 miles from it. Proceeding thus in a south-easterly direction, the specific gravity fell rapidly from 1·02692 off St. Iago on the 10th August, to 1·02632 on the 12th, after which it retained the low mean specific gravity of 1·02627 until the 21st August, when the course was changed to a westerly one along the equator. The specific gravity of the water on this day was the lowest hitherto registered for a surface-water; it was 1·02601, in lat. 3° 8′ N., and on the boundary line between the equatorial and Guinea currents. The same low specific gravity was observed in following the equatorial current as far as St. Paul's rocks, after which it quickly rose as the Brazilian coast was approached; and the maximum of 1·02786 was obtained on the 26th September, when off the entrance to Bahia, in latitude 13° 4′ S.

The observations in the South Atlantic were limited to a line down the western side as far as the Abrolhos Bank, and thence across to the Cape of Good Hope. In the region of the south-east trade-wind, therefore, we have only a few observations close to the coast; and as we have seen in the North Atlantic, on the voyage from Teneriffe to St. Thomas's, the specific gravity is higher in mid-ocean than either on the east or the west side, so in the South Atlantic it is possible that the same may hold good. From the Abrolhos Bank to Tristan d'Acunha the specific gravity sinks steadily from 1·02785 to 1·02606, and from Tristan to the Cape of Good Hope, along a course lying between the 35th and the 37th parallels of south latitude, the mean specific gravity was 1·02624. Between the same parallels of north latitude the mean specific gravity was 1·02713.

It must be remembered that the results obtained can only be held good for the season of the year in which they were observed, and that the observations in different latitudes were made in different seasons, and, further, that all the observations north of the line as far as 20° N. were obtained on the eastern side, and those to the southward of it as far as 30° S. were obtained on the western side of the ocean; so that it would be unwise to attempt to draw any general conclusions from such imperfect data. Considering, however, our four parallel sections, we have at least this positive result—that in the month of June and mean latitude 36° N. the surface-water in mid-ocean has a mean specific gravity of 1·02713, that in the months of February and March and mean latitude 22° N. the mean surface specific gravity is 1·02773, that in the month of August and mean latitude 2° N. it is 1·02624, and that in the month of October in mean latitude 36° S. it is 1·02621.

On the way to and from Halifax in the month of May some observations were obtained in the cold water with which the north-eastern coast of America is surrounded, the mean specific gravity being 1·02463. On the 1st May in the Gulf-stream the specific gravity of the water was 1·02675, and its temperature 23°·9 C.; and the next day it was 1·02538, and the temperature 13°·3 C. If the results be reduced to their values at the respective temperatures of the different waters, we have for the specific gravity of the Gulf-stream water 1·02445, and of Labrador-current water 1·02584; so that the fall of temperature very much more than counterbalances the want of salt in the water. In the same way we find the mean specific gravity of the water referred to the temperature which it has in the ocean to be—in latitude 36° N. and month of June 1·02548, in 22° N. and months of February and March 1·02592, in 2° N. and month of August 1·02335, and in 36° S. and month of October 1·02659.

Leaving Simon's Bay on the 17th December, 1873, the ship proceeded in the direction of the Marion Islands. Immediately outside the Cape the warm water of the Agulhas current was met with, which possessed a comparatively high specific gravity, averaging on the 18th, 19th, and 20th December 1·02657 at 15°·56 C., and 1·02477 at the average temperature (21°·9 C.) of the water. As we advanced in a southerly direction, the specific gravity as well as the temperature sank rapidly; and on the 26th, when off the misty and snow-capped islands of Marion and Prince Edward, the surface was 5°·3 C. and the sp. gr. 1·02518. After leaving these islands, and until on the way northward to Australia we had passed the 50th parallel of south latitude, the specific gravity of the surface remained remarkably uniform. Between the Marion Islands and Kerguelen's Land the average specific gravity was 1·02512, between Kerguelen's and the edge of the pack-ice it was 1·02506, along the verge of the pack-ice it was 1·02476, and between the pack-ice and the 50th parallel it was 1·02514; thence to the Australian coast it rose daily, reaching 1·02638 off Cape Otway. Except when amongst loose ice, there was hardly any variation at all in the specific gravity all the way between Marion Island and the 50th parallel; when amongst the ice the specific gravity was liable to sudden and considerable fluctuations, going down on the 14th February to 1·02419, and on the 18th to 1·02418, the ship being on both occasions surrounded by broken pack-ice. During the same trip the specific gravity at the temperature of the water was also very uniform, the mean being 1·02690.

Leaving Sydney a loop-like course was made, by way of New Zealand, Tongatabu, and the Fiji Islands, back to the Australian coast at its northernmost point, Cape York. The mean specific gravity of the western part of the sea between Australia and New Zealand was 1·02647, and that of the eastern part 1·02622, while in Cook's Strait itself it was only 1·02593. Between New Zealand and the Kermadecs the average specific gravity was 1·02630, and between the Kermadec Islands and Tongatabu it was 102651; round the Fijis it was 1·02661; and between the Fijis and Cape York a very uniform specific gravity was maintained, the mean being 1·02643. We thus see that in the western part of the Southern Pacific the specific gravity of the surface-water is very uniform, varying but little with latitude, showing a very marked difference from the Atlantic Ocean, a difference which was observed to obtain in all parts of the Pacific.

From Cape York to Hong Kong the course lay through the remarkable series of so-called enclosed seas. The mean surface specific gravities in these seas were as follows:—In and around Torres Straits, 1·02655; in the Arafura Sea, 1·02549; in the Banda Sea, 1·02603; in the Molucca Passage, 1·02517; in the Celebes Sea, 1·02562; in the Sulu Sea, 1·02496; in the sea enclosed by the Philippine Islands, 1·02532; and in the China Sea, 1·02518. On the way to Hong Kong we traversed the Sulu and China seas just at the time when the south-west monsoon had ceased and the north-east one began to blow. When we returned by the same route as far as the south point of Mindanao, the north-east monsoon had already persisted for more than two months; and the effect of the comparative dryness of this wind is very evident in the surface specific gravities. The following average values were found:—In the China Sea, 1·02534; in the Philippine Sea, 1·02532; and in the Sulu Sea, 1·02570. On the other hand, the few observations made in the northern part of the Celebes Sea showed a diminution of specific gravity, the average being 1·02496. Outside the south point of Mindanao a strong and steady north-easterly wind was met with, and for the next ten degrees in longitude the mean specific gravity was 1·02596. On nearing the coast of New Guinea the specific gravity went down rapidly, averaging for a few days before our arrival at Humboldt Bay 1·02519. That a very large river must here empty itself into the sea was evident from the amount of drift-wood with which the sea was covered, and from the superficial distribution of the light water. The specific gravity of water at 50 fathoms below the surface was almost perfectly uniform, varying from 1·02611 to 1·02636 during the whole cruise from Mindanao to Admiralty Island. When about twenty miles off Humboldt Bay the specific gravity of the water fell as low as 1·02420. Between Humboldt Bay and the Admiralty Island the surface specific gravity was very uniform, varying from 1·02583 to 1·02600, except in one position (lat. 2° 30′ S., long. 144° 7′ E.), where it fell to 1·02554; but a series of observations on waters taken from different depths at this position showed at once the superficial nature of the variation; the water at 10 fathoms from the surface had a specific gravity of 1·02580. Although there was here no drift-wood to be seen, I have little doubt that we had to do with warm water, although the nearest point of New Guinea was at least 80 miles distant; and indeed Capt. Scoresby, who sailed along this coast much closer in shore, observed in this part large quantities of drift-wood, and inferred the existence of a large river in the neighbourhood.

North of Admiralty Island the specific gravity is somewhat higher; between the equator and 3° north latitude the mean is 1·02648; thence all the way north to Japan it remains very uniform, the mean being about 1·02600.

Leaving Japan in the month of June, the course lay entirely between the parallels of 34° and 40° N. as far as the meridian of 155° W. The specific gravity was slightly greater on the western side of the ocean than on the eastern. The following mean specific gravities were observed for every ten degrees of longitude:—

140° to 150° E.	1·02586.
150 to 160	1·02574.
160 to 170	1·02585.
170 to 180	1·02568.
180 to 170 W.	1·02569.
170 to 160	1·02544.
160 to 155	1·02532.

Arrived at 155° W. longitude, a southerly course was pursued by way of the Sandwich Islands and Tahiti, when the following mean specific gravities were observed:—

35° to 25° N.	1·02618.
25 to 15	1·02593.
15 to 5	1·02574.
5 N. to 5 S.	1·02649.
5 S. to 15	1·02658.
15 to 25	1·02699.
25 to 35	1·02620.

Whence it will be seen that the minimum value is reached between 15° and 5° N. latitude, the lowest value actually observed having been 1·02488 in latitude 7° 26′ N. The maximum to the south between 15° and 25° is very much more pronounced than that to the north of it; in fact round about Tahiti is the only spot in the Pacific where I have observed the specific gravity reaching 1·02700; the actually highest observed value was 1·02728 on the 3rd October, when the ship was being swung a few miles off Papeete Harbour.

The easterly course to Valparaiso was made principally between the parallels of 35° and 40° S. latitude. From 125° W. longitude to Valparaiso the mean specific gravity was 1·02534, the maximum being 1·02552 and the minimum 1·02513.

A large number of observations on the specific gravity of the waters at the bottom and intermediate depths have been made. In a preliminary report like the present it would be out of place to enter upon the discussion of so extensive a subject, even did the time at my disposal admit of my attempting it. I therefore content myself with giving the numerical results. It is to be hoped that in the homeward cruise through the Atlantic a more complete series of observations in this direction may be obtained, as those obtained on the way out were only sufficient to show that this ocean, and especially its northern part, differs greatly from the rest of the world-sea in density, as it does in temperature and in many other particulars. As a general rule, in both oceans between the parallels of 40° N. and 40° S. the specific gravity (reduced to 15°·56 C.) is greatest at or near the surface, and decreases more or less regularly until a minimum is reached, generally about 400 fathoms from the surface, when there is a slow rise, the bottom-water being rather heavier. This general law obtains in the Pacific and in the South Atlantic; but from the few observations obtained in the North Atlantic, there are indications of a departure from it. Although in the case of surface-water the variations of specific gravity with latitude are very considerable, more especially in the Atlantic, the water below 200 fathoms presents great constancy, the variations being comparable with those of the temperature at the same depths. In intertropical regions, and generally where there exist alternating wet and dry seasons, there are usually more than one maximum and minimum in the series between the surface and the bottom. How long it takes in quiet seas for fresh water to diffuse downwards in the sea, will be seen by inspection of the results obtained on the 22nd February, 1875, above referred to, when about 80 miles off the mouth of one of the large rivers of New Guinea, and the sea covered with driftwood. The specific gravity was at the surface 1·02537; at 10 fathoms, 1·02578; at 20 fathoms, 1·02584; at 40 fathoms, 1·02594; at 50 fathoms, 1·02636; and at 100 fathoms, 1·02658, where it obtained its maximum, the temperature being sensibly the same down to 50 fathoms, namely from 28° C. to 28°·4 C.

Observations on the Carbonic Acid contained in Sea-water.

The carbonic acid when boiled out of the water is received by baryta-water of known strength; its consequent loss of alkalinity is measured by hydrochloric acid of corresponding strength. Having observed that the presence of sulphates in sea-water is one of the potent agents in the retention of the carbonic acid*, I always add 10 cub. centims. of a saturated solution of chloride of barium to the water before commencing the operation. This facilitates greatly the liberation of the carbonic acid, and also causes the water to boil tranquilly, even to dryness, without showing any tendency towards bumping. The quantity of water used has been almost invariably 225 cub. centims., and the property possessed by sea-water of retaining its carbonic acid with great vigour makes it possible to perform the determination of it even a couple of days after its collection. As a proof of this, on the 10th July, 1875, the surface-water was found when freshly drawn to contain 0·0291 gramme carbonic acid per litre. A quantity likewise of the freshly drawn water was boiled *in vacuo* for an hour and fifty minutes in order to collect the oxygen and nitrogen, and then allowed to cool protected from the air. One portion of this water was exposed to the air in a flat dish outside the port for three hours, and in another portion the carbonic acid was at once determined. It contained 0·274 gramme per litre, whilst the water exposed to the air contained 0·6273 gramme. The effect, then, of boiling *in vacuo* was only to remove about 5 per cent. of the whole amount, whilst free exposure to the air had no effect whatever. As the determination of the carbonic acid takes a considerable time, it is only by taking advantage of this property that I have been able to determine it in samples from depths in the same locality; for where boiling *in vacuo* has so little effect, there is no danger of losing carbonic acid when the water is carefully decanted.

---

* Proc. Roy. Soc. 1874, vol. xxii. pp. 483–495.

As in the great majority of cases, where the carbonic acid has been determined, the oxygen and nitrogen have also been collected, and are being preserved until our return home, when they will be analyzed: it would be useless to attempt to discuss the results of the carbonic-acid determinations at present, and before these analyses have been made, especially as there is likely to be some relation between the amounts of oxygen and of carbonic acid. Independently, however, of the relations which may subsist between the two bodies, it may be gathered from the inspection of the accompanying Table that, taking surface-waters alone, the amount of carbonic acid present is many times greater than would be contained in the same volume of distilled water under the same circumstances. I have again and again exposed distilled water, surcharged with carbonic acid, to the air, and after even a very few minutes the carbonic acid was completely gone; on adding to 225 cub. centims. of it 5 cub. centims. baryta-water, the mixture remained perfectly clear; and on titrating with hydrochloric acid there was no diminution of alkalinity.

The temperature of the water on this occasion was 18°·3 C. On that particular day, namely the 8th July, 1875, when in the middle of the North Pacific, there was no determination made of the carbonic acid in the surface-water; but two days later, when the temperature of the surface-water was 18°·9 C., 225 cub. centims. of it contained 0·0066 gramme carbonic acid. Had there been 0·002 gramme CO_2 in the 225 cub. centims. distilled water, it must have been detected and determined. Hence, under the same circumstances, this particular sea-water, whose specific gravity was 1·02528 (at 15°·56 C., water at 4° = 1), contained at least thirty times as much carbonic acid as an equal bulk of fresh water would have done. Further, as might have been expected from the above observations, the amount of carbonic acid contained by surface-waters of the same temperatures increases with the density, and consequently is greater in the surface-water of the Atlantic than in that of the Pacific, the two oceans being very markedly distinguished from one another by the different densities of their surface-waters. Thus we have a mean of 0·0466 gramme CO_2 per litre in Atlantic surface-water of temperature between 20° and 25° C. and mean density 1·02727; whilst in the Pacific the mean is 0·0268 gramme in water of 1·02594 mean density; and the mean amount of carbonic acid in Atlantic water of temperature above 25° C. and mean density 1·02659 is 0·0409, whilst in the Pacific the corresponding water is of mean density 1·02593, and contains 0·0332 gramme CO_2 per litre. As a rule, other things being equal, the amount of carbonic acid diminishes as the temperature increases; thus the mean amount of carbonic acid in waters whose temperature was between 15° and 20° was found to be 0·0446 gramme per litre, the mean density being 1·02642, whilst we have seen that in the Atlantic the surface-water of temperature above 25° C. and of mean density 1·02659 contains 0·0409 gramme per litre. Also there is usually more carbonic acid in waters taken from the bottom and intermediate depths than in surface-water; but if regard be had to the temperature of the water, it will be seen that there is but little difference in the amount in waters of the same temperature from whatever depth they may have been derived. This seems to indicate that the animal life at the bottom and at great depths cannot be very abundant, otherwise there could hardly fail to be a decided excess of carbonic acid in the deep water, owing to constant production and want of the means of elimination of the gas. On this subject, however, it would be premature to speculate before the determination of the oxygen, from which we may hope for much information.

I have made a number of experiments to detect the presence of carbonates in sea-water. If any were present, they should be found in the residues from the determination of the carbonic acid; and I had been in the habit of testing by adding a little acid to them, and invariably with the same result—that carbonates were not present; at the same time it appeared to me to be very unlikely that such should be the case, when there is plenty of carbonate of lime in the shells of the animals living and dying in it, and also plenty of carbonic acid in the water to dissolve it. It was also not improbable that the very considerable amount of sulphate of baryta in the residues might disguise the effervescence. I therefore evaporated a separate portion (about 150 cub. centims.) of the water in a platinum dish to dryness, removed the soluble salts with a little water, and added a few drops of strong hydrochloric acid, which was allowed to flow slowly over the inner surface of the dish, when even the smallest trace of carbonates could be detected by the appearance of minute bubbles on the platinum surface. In this way I have examined a number of waters between Tahiti and Valparaiso, and with the general result that in ocean-water carbonates are never present except in small quantities, and in many samples they have been absent altogether. They are generally present in waters at or near the surface, disappearing, however, as the depth from which the water has been taken increases. They are generally, though not invariably, absent in waters from greater depths than 400 fathoms. They are present or absent in bottom-water according to their occurrence in the bottom; although here also there appears to be exceptions, as I have observed water taken from a "*Globigerina*-ooze" bottom which contained no carbonate.

In connexion with carbonic acid I may mention that I have frequently tested waters, and especially bottom-waters, for organic matter. None of the methods in use for determining this substance in drinking-water giving satisfaction when applied to sea-water, I had to content myself with endeavouring to detect its presence. If the jelly-like organism which had been seen by some eminent naturalists in specimens of ocean bottom and called *Bathybius* really formed, as was believed, an all-pervading organic covering of the sea-bottom, it could hardly fail to show itself when the bottom-water was evaporated to dryness and the residue heated. In the numerous samples of bottom-water which I have so examined, there never was sufficient organic matter to give more than a just perceptible greyish tinge to the residue, without any other signs of carbonization or burning. Meantime my colleague, Mr. Murray, who had been working according to the directions given by the discoverers of *Bathybius*, had actually observed a substance like "coagulated mucus," which answered in every particular, except the want of motion, to the description of the organism; and he found it in such quantity that, if it were really of the supposed organic nature, it must necessarily render the bottom-water so rich in organic matter that its presence would be abundantly evident when the water was treated as above described. There remained, then, but one conclusion, namely, that the body which Mr. Murray had observed was not an organic body at all; and on examining it and its mode of preparation I determined it to be sulphate of lime, which had been eliminated from the sea-water, always present in the mud, as an amorphous precipitate on the addition of spirit of wine. The substance when analyzed consisted of sulphuric acid and lime; and when dissolved in water and the solution allowed to evaporate, it crystallized in the well-known form of gypsum, the crystals being all alike, and there being no amorphous matter amongst them.

These observations were made chiefly on the voyage from Hong Kong to Yokohama in the first quarter of the year 1875; and it subsequently occurred to me that an approximate determination of the organic substance in sea-water might be effected in the following way:—Supposing the amount of carbonic acid in the water to be known, let a little permanganate of potash be added to a sample of it, and let the carbonic acid be determined in the usual way by boiling the solution. If the water contained any easily oxidizable carbon compound, we should obtain more carbonic acid in the second than in the first determination, and the difference would correspond approximately to the amount of organic carbon present. In several waters which I have treated according to this principle, I have found from two to five milligrammes of carbon per litre.

Observations on the occurrence of Manganese Nodules on the Sea-bottom.

Occasionally pieces of stone of a black colour have been brought up, and been found to consist of peroxide of manganese mainly. Several interesting specimens were obtained between Bermuda and the Azores, which were apparently steps in the formation of the black substance out of concretions of the bottom at the place in question. They were obtained on the 17th and 27th June, and may be divided into four classes:—1st, those which contain no manganese at all; 2nd, those where the manganese formation has commenced; 3rd, those where it is well advanced; and 4th, those where the bulk of the substance is peroxide of manganese. Those of the first class are, as far as can be learned from qualitative analysis and microscopical examination, merely mechanical aggregations of the bottom existing at the place in question. Of a white colour, and generally the same appearance, are those of the second class; they contain, however, numerous perforations, whose walls are lined with a very thin black film peculiarly striped. On treating with dilute hydrochloric acid, the mass is found to consist chiefly of carbonate of lime with a considerable quantity of clay. Strong hydrochloric acid decomposes the latter, when a certain amount of chlorine is given off. In another concretion, belonging to the same class, the manganese is seen forming in minute mammillary concretions on the outside surface, as well as on the tube linings. Belonging to the third class is one (also brought up on the 27th June) where the outside is wholly covered with oxide of manganese; and in cutting through the substance of the stone, the layer is seen to be of a sensible thickness; also all the worm-holes are seen to be completely coated; and numerous more minute holes are found, all of which are coated in the same way. A very considerable percentage of the whole mass has thus become manganese. On the face of a fresh cutting the interior of the mass may be seen to preserve its white colour. From the edge of the black layer inwards, however, the mass is stained of a brownish colour, which gradually disappears towards the centre. Blackish brown veins are also seen to traverse the whole mass. Pulverized, it effervesces strongly with dilute hydrochloric acid. The residue is easily decomposed by strong acid, evolving large quantities of chlorine; silica is left undissolved with a little sand. In the hydrochloric-acid solution there was found, besides alumina, manganese, and a little iron, a certain quantity of nickel and cobalt. A concretion of the fourth class came up on the 17th June. It is an irregular nodule, about 1½ inch long, of a brownish-black colour, having its outside surface mammillated all over. This mammillated surface is so peculiar that, by its means, the manganese may be at once recognized. When broken it is found to consist of irregularly concentric layers of peroxide of manganese, alternating with fine seams of calcareous and earthy matter. It contains a small, white, earthy nucleus. The broken surface resembles the figuring of polished walnut wood. It consists of peroxide of manganese, alumina, iron, silica, small quantity of lime, magnesia, cobalt, and phosphoric acid. Heated in the tube it gives out, like all these concretions, water with a strong alkaline reaction.

The most remarkable occurrence of peroxide of manganese on the bottom was met with on the 18th February, in latitude 35° 45′ N. and longitude 20° 12′ W. The dredge was put over in 1500 fathoms, and came up full of dead coral of a jet-black colour on the surface. Some of the sticks adhered to large black masses, and on breaking them the inside was seen to be perfectly white, the black substance forming merely a very thin rind which cracked off easily on receiving a smart blow. This black rind, as well as the masses to which some of the sticks were attached, consisted of peroxide of manganese, the white part or inside having the composition of ordinary coral (chiefly carbonate of lime). The black masses to which some of the sticks were attached present, like the concretions already described, a minutely mammillated appearance on the outside, and when broken across are seen to consist of concentric layers, blacker and more compact towards the outside, and browner and more earthy towards the inside. The layers are separated from each other by numerous very fine layers of mud, chiefly carbonate of lime. They increase in number towards the inside, and in some instances can be seen to be composed in part of fragments of foraminiferous shells. The black mass was found on analysis to consist of peroxide of manganese, alumina, oxide of iron, silica, small quantities of lime and magnesia, and traces of copper, cobalt, and phosphate of lime. Compared with the manganese concretions already described, they appear to have the same chemical composition, and their internal structure in layers points to a similar mechanical origin; in fact they differ from the others only in being fragments of much larger concretions. Where the coral sticks adhere, they do not penetrate into the mass at all, but their flat roots are as sharply divided from the black mass as the black rind is from the inside coral.

On the 27th June, amongst the concretions, a fragment of slate, coated on the outside with mammillated peroxide of manganese, was brought up.

The preceding notes on the occurrence of the manganese nodules was written at the Cape of Good Hope, and sums up our knowledge of the subject at the close of the Atlantic cruise. In the Antarctic Ocean the soundings obtained showed in a remarkable manner the general comparative shallowness, the depth being in general under 2000 fathoms. Whenever the dredge or trawl was used in that ocean it brought up large quantities of stones; but they were invariably fragments, more or less rounded, of granitic and igneous rocks, and I did not notice any manganese. On the 13th of March, however, when approaching Australia, the depth increased to 2600 fathoms; a very large haul of manganese nodules was obtained, presenting the same general characteristics as those in the Atlantic. In the Pacific the amount of manganese found has been immense, there being hardly a sounding where it could not be detected in small particles amongst the mud; and, indeed, in many parts the nodules occur in such quantity that the sounding-tube has brought them up in considerable numbers at one time; they have also frequently come up sticking to the bottom of the water-bottle. Here, however, they have chiefly come under the observation of my colleague Mr. Murray, and will be treated of in his Report. Chemically they are very much alike, as far as quantitative analysis can supply information. They all contain one of the higher oxides of manganese in preponderating amount, cobalt and nickel in notable quantity, and copper in traces, besides argillaceous and often sandy matter. I hope, when the cruise is over, to be able, by means of quantitative analysis, to render a detailed account of their nature, from which it may perhaps be possible to obtain some hints as to their origin and development.

Since the discovery of this most remarkable and unexpected occurrence of a mineral, having much resemblance to psilomelane, evidently forming at the bottom of the sea, I have taken every opportunity of examining specimens of peroxide of manganese from terrestrial sources; and in many cases I have found them to resemble the marine mineral in several points, especially in nodular structure and in giving off alkaline water when heated. Some peroxide of manganese which I got from the mines near Paarl, about thirty miles from Cape Town, had most perfectly nodular structure, but was extremely hard, whereas our nodules, when freshly brought up, can generally, although not invariably, be easily cut with a knife; but they increase very markedly in hardness when exposed to the air, even for only a few weeks. I do not attach very much importance to the fact of its giving out alkaline water, for this is a property which I have found to be very generally possessed by rocks and minerals. Of the zeolites, for instance, which were found in Kerguelen, there was not one which did not give out alkaline water with a very perceptible empyreumatic smell when heated.

It has been mentioned above that the dredge frequently brought up large quantities of stones in the Antarctic Ocean. Amongst them were almost invariably fragments of granite or syenite, as well as of both basalt and trachyte. On the 2nd February, 1874, when between Kerguelen and Heard Islands, a very large quantity of stones was brought up in the dredge from a depth of 150 fathoms. Amongst them were a piece of granite, also two varieties of basalt, one coarse-grained with porphyritic olivine, and the other exceedingly fine-grained and compact, without any separate crystals being visible to the naked eye. It was chiefly remarkable from the fact that the stones, though fresh from the bottom and still quite wet outside, were, when broken, perfectly dry inside, the moisture not having penetrated beyond the thickness of a sheet of paper. The edges of these stones were less rounded than those of the other species which accompanied them. In order to be perfectly sure that there was no mistake, I broke about a dozen of them, the species being easily recognized by the edges of the stones being less rounded than those of the others, and always with the same result; while those of the other species were not only wet inside, but, especially in the trachytic ones, decomposition in concentric shells had made considerable advances. As a drop of water applied to the fractured face was readily and quickly absorbed, I can only account for the dryness inside by considering that the stones in question had passed but a very short time under water. As they were found in lat. 52° S., and the first iceberg was only met with in 60° S., it would be difficult to imagine that they had come ice-borne from the Antarctic land; at the same time it was equally difficult to imagine any other adequate means of conveyance than ice. I believe that they come from Heard Island, whose ice-bound shores are constantly despatching miniature bergs into the sea, which, from their insignificant size, would suffer rapid destruction alike from the violence of the seas and from the temperature of the water, which, on the occasion in question, was between 3° and 4° C. Many small ice-masses, such as I have supposed, were floating off the southern shore of Corinthian Bay, which on this side had a continuous icy coast-line formed by a glacier descending from the central high grounds which culminate in Kaiser Wilhelm Peak, and reaching the sea both on the west and on the east side of the inhabited isthmus, as I have described in my short note on the island. The position where the stones were dredged is within 100 miles of Heard Island, and through the above-mentioned agency there must be a constant conveyance of the *débris* of the island out to sea, which would account for the very stony character of the bottom found.

Observations on Sea-water Ice.

Many different opinions have been expressed as to the nature of ice resulting from the freezing of sea-water, all agreeing, however, in one point, that when melted the water is unfit to drink. During the Antarctic cruise I took an opportunity of examining some of the broken pack-ice, into which the ship made an excursion on the morning of the 25th of February, and also some ice which had formed over night in a bucket of sea-water left outside the laboratory port.

The piece of pack-ice which I examined was in substance clear, with many air-bells, most of them irregularly shaped. Two portions of this ice were allowed to melt at the temperature of the laboratory, which ranged from 2° to 7° C. The melting thus took place very slowly, and made it possible to examine the water fractionally. My experiments consisted in determining the chlorine in the water by means of tenth-normal nitrate of silver solution, and observing the temperature of the ice when melting.

A lump, which when melted was found to measure 625 cub. centims., was allowed to melt gradually in a porcelain dish. When about 100 cub. centims. had melted, 50 cub. centims. were taken for the determination of the chlorine; they required 13·6 cub. centims. silver solution, corresponding to 0·0483 gramme chlorine. When 560 cub. centims. had melted, 50 cub. centims. were titrated, and required 1·6 cub. centim. silver solution, corresponding to 0·0057 gramme chlorine. The remainder (65 cub. centims.) of the ice was then melted and 60 cub. centims. titrated; they required 0·39 cub. centim. silver solution, corresponding to 0·0014 gramme chlorine. We have, then, in the first 50 cub. centims. 0·0483 gramme chorine, in the next 510 cub. centims. 0·0579 gramme chlorine, and in the last 65 cub. centims. 0·0015 gramme. Hence the whole lump (625 cub. centims.) contained 0·1077 gramme chlorine, or, on an average, 0·1723 gramme chlorine per litre. A qualitative analysis of the water showed lime, magnesia, and sulphuric acid to be present.

Another piece of the ice was pounded and allowed to melt in a beaker. When about half was melted, the water was poured off and found to measure 95 cub. centims.; 75 cub. centims. were titrated with silver solution, and required 1·9 cub. centim. The remainder, when melted, measured 130 cub. centims., and required 0·9 cub. centim. silver solution. Hence the first fraction of 95 cub. centims. contained 0·0085 gramme chlorine, and the second of 130 cub. centims. 0·0032 gramme chlorine. The whole quantity (225 cub. centims.) of ice, therefore, contained 0·0117 gramme chlorine, or, on an average, 0·0520 gramme per litre.

From these results it is evident that the ice under examination was very far from being an homogeneous body; and, indeed, nothing else could be expected, when it is borne in mind that the ice in question owes its existence, not only to the *bonâ fide* freezing of sea-water, but also to the snow which falls on its surface and is congealed into a compact mass by the salt-water spray freezing amongst it.

The ice formed by freezing sea-water in a bucket was found to have formed all round the bottom and sides of the bucket, and forming a pellicle on the surface, from which, and from the sides and bottom, the ice had formed in hexagonal planes, projecting edgewise into the water. The water was poured off, the crystals collected, washed with distilled water, pressed between filtering-paper, and one portion melted. It measured 9 cub. centims., and required 4 cub. centims. silver solution, corresponding to 0·0142 gramme chlorine, or 1·5780 gramme per litre. The other portion was used for determining the melting-point. The thermometer used was one of Geissler's *normal* ones, divided into tenths of a degree Centigrade, whose zero had been verified the day before in melting snow. The melting-point of the ice-crystals was found to be −1°·3. The temperature of the melting mass was observed to remain constant for twenty minutes, after which no further observations were made.

In the same way the melting-point of the pack-ice was determined. The fresh ice began to melt at −1°; after twenty minutes the thermometer had risen to −0°·9, and two hours and a half afterwards it stood at −0°·3, having remained constant for about an hour at −0°·4. Another portion of the ice rose more rapidly; and when three fourths of the ice was melted, the thermometer stood at 0°.

These determinations of the temperature of melting sea-water ice show that the salt is not contained in it in the form of mechanically enclosed brine only, but exists in the solid form, either as a single crystalline substance, or as a mixture of ice and salt crystals. Common salt, when separating from solutions at temperatures below 0°, crystallizes in hexagonal planes; sea-water ice, therefore, may possibly have some analogy to the isomorphous mixtures occurring amongst minerals.

A very important practical consequence follows from these observations, namely, that pack-ice, though unfit to drink when a lump of it is melted as a whole, may serve as a source of fresh water if melted fractionally. As the melting-point of the salt ice is lower than that of pure ice, it melts first, and at the same time, by keeping down the temperature of the mass to its own melting-point, it prevents any of the fresh ice being wasted. When the salt ice has all been melted the brine may be thrown away, and the remainder of the ice will supply fresh water. If a thermometer be kept in the ice during the process of melting, it will indicate by its reading when drinkable water is being formed.

Observations made on Shore in some of the Islands visited.

Viewed from the sea, the island of St. Vincent, one of the Cape-Verd group, presents an extremely rugged and desert appearance, which it preserves even upon the closest inspection. The hills round the harbour consist of interbedded igneous rocks, the individual beds being seldom over three or four feet thick, and generally only about two feet, dipping at a gentle angle away from the centre of the harbour. These beds are much cut up by vertical dykes of basaltic rock running in two principal directions, namely, north and south and east and west. They frequently present an eminently columnar cleavage in the direction of their breadth. Many of the beds which form the mass of the hill are of similar nature and cleave in the same way. The rock on each side of these basaltic masses, whether beds or dykes, is generally much altered, and has suffered considerable disintegration and decomposition, being frequently transformed into a mass of kaolin in the neighbourhood of the basalt.

The effect of heat in rendering many minerals which occur in igneous rocks decomposable by acids is well known, and may furnish an explanation of the above-named phenomena. As the dykes extend to the very tops of the hills, and the adjacent rock is weathered away leaving them projecting, the outline of the hills gets a peculiar serrated appearance, which is very characteristic of the island. The spurs which project from the main ranges into the plains are always found to depend for their height and direction on one of these basaltic dykes, which can be followed all the way along their crest.

In many of the rocks, where their character is cellular, their cells are filled with geodes, in some cases of carbonate of lime, and in others of zeolite. The rocks are nearly all of a porphyritic character from crystals of augite separated out. The most common rock contains large augites in a light grey ground-mass. The crystals are frequently arranged in bands with their longer axes parallel to each other and in the direction of the bands. Nothing approaching to either obsidian or pumice was observed in any part of the island. Besides the igneous rocks, there is in the plain on which the town stands and to the south of it a calcareous formation consisting of shells, corals, and rounded pebbles of the neighbouring rocks, united by a firm paste of a white and sometimes of a reddish colour; also, from the constant prevalence of winds from one quarter, the sand from the beach has been distributed over the plains and in the valley. At the south side of the harbour there are dunes of blown sand, which in some places is consolidated into rocks similar to those of Bermuda. Here, however, the sand does not consist purely of carbonate of lime, but of the *débris* of shells and volcanic material mixed. Hence the consolidation of it into rock is not so easy, even if there was the quantity of rain to do it. On the sand hills the wind produces the usual beautiful ripple-mark, and the mixed character of the sand makes the levigating action of the wind very apparent, the light calcareous particles being swept into the eddies under the crest of the ripple, the heavy volcanic *débris* remaining on the surface. As the colour of the latter is generally black and that of the former white, a sand hill looks lighter or darker according as it is viewed from the weather or from the lee side.

We were told that on the other side of the island there were tolerably perfect craters; we were, however, unable to visit them. In the neighbourhood of the harbour there was no vestige of recent volcanic action. At St. Paul's rocks the ship was made fast to the rocks, and as we remained there over thirty-six hours we had ample time to thoroughly explore them. They were visited by Darwin in the 'Beagle,' and several times later by other ships. As the nature of the rocks appears to present some difficulty to geologists, I made as complete a collection of them as I could, and they will be sent home with the other collections from this place. The white enamel-like incrustation mentioned by

Darwin, I found only on the southern island. On the northern island the bulk is composed of what I take to be Darwin's "yellowish harsh stone, split up into numerous pseudo-fragments." These last have an appearance which recalls that of weathered orthoclase crystals. All of these rocks give off alkaline water when heated in the closed tube, and consist of hydrated silicate of magnesia with alumina and protoxide of iron in subordinate quantity. They may therefore, I think, be classed as serpentine; and the above-mentioned resemblance to orthoclase crystals may perhaps afford some indication of the parent rock. Of the more recent veins mentioned by Darwin, some are bordered on both sides by black bands. These bands consist of a hard infusible substance. The powder has a dirty greyish green colour, and effervesces with dilute hydrochloric acid, leaving a brown insoluble residue. In strong hydrochloric acid it dissolves with evolution of chlorine, and the colour phenomena of dissolving peroxide of manganese. It was found to consist of phosphate of lime, peroxide of manganese, a little carbonate of lime and magnesia, and traces of copper and iron. Like the other rocks it gives off alkaline water in the closed tube.

At Fernando Noronha some of the smaller islands at its N.E. extremity were visited. The highest of these, St. Michael's Mount, forms one of the prominent peaks which are characteristic of the group. It is very steep and formed entirely of phonolite, which occurs columnar at the base and massive towards the top. On the western side, where we landed, the columns are inclined to the horizon at an angle of about 30°. Their transverse section looks nearly square, the corners, however, being considerably rounded off. The columns are for the most part slender, and their mass is of a dirty green colour. In this the sanidin crystals are arranged with great regularity, with their broadest faces in a plane perpendicular to the length of the column. The sides of the mount are covered with loose blocks of massive phonolite fallen down from above, and retained in position on a very steep incline by the branches of most luxuriant creeping plants. On the weathered sides of these blocks the sanidin crystals, and also the hornblende ones, though in less degree, project sometimes as much as a quarter of an inch. This rock possesses also, in a most eminent degree, the characteristic property from which it has derived its name of phonolite; when struck with the hammer it rings like a bell. The mount is cleft from top to bottom in two places, nearly at right angles to each other. These clefts are filled up with a hard flinty looking substance, which appears from its structure to have been gradually deposited by water trickling down the sides. Its mass is concretionary and sometimes foliated; its colour is white, to yellowish white or brownish yellow. It scratches glass with ease, and does not effervesce with acid. Plates of 2 to 3 millims. thickness are quite translucent. Heated in the forceps it does not fuse, but turns perfectly white, and is then easily crumbled between the fingers. In the closed tube it gives off alkaline-reacting and empyreumatic-smelling water. It was found to consist of phosphate of alumina and iron, with some silicate and sulphate of lime.

Besides St. Michael's Mount, Rat Island and Platform Island were landed upon. Rat Island is the largest of the secondary islands, and the one most distant from the main island. It is composed on the western side of massive basaltic rock, and on the eastern of sandstone. This latter probably overlies the basalt, as in its structure it bears the marks of having been deposited in drifts, and the sand is calcareous, consisting of shell *débris*. On our way to and from Rat Island we had to pass all along the western side of Booby Island. The wave-worn cliffs showed that the island was entirely formed of the above-mentioned calcareous sandstone. No igneous rock was visible at all; and as the peculiar wind-blown stratification marks are continued below the level of the sea, it is probable that the land here is sinking, or at least has sunk.

Platform Island consists of a mass of perfect basaltic columns rising out of the water, and supporting a covering of massive basalt, on which is spread out the platform of calcareous rock, on which are the ruins of an old fort, and from which the island doubtless takes its name.

A day was spent on each of the islands of the Tristan d'Acunha group. It consists of three:—Tristan, the largest, Inaccessible, and Nightingale. The last is more properly a group of islands studded all round with isolated rocks. The difficult nature of the ground in Inaccessible and Nightingale, and that combined with the uncertain state of the weather when at Tristan, rendered excursions to a distance from the landing-place impossible. The rock specimens, therefore, which have been collected are all from the neighbourhood of the landing-places. Each island has its distinctive features. Inaccessible is a raised plateau, bounded on all sides by cliffs over 1000 feet high, which plunge directly into the sea. Looked at from the sea, there is no appearance of a crater on the top, the only inequalities in the surface being apparently due to erosion. The waterfalls, which tumble from the cliffs, afford most picturesque proof of the abundance of water above. Tristan Island, like Inaccessible, consists of a very similar plateau, bounded by cliffs of about the same height and almost equally impracticable. This plateau, however, is surmounted by a lofty peak rising to the height of 8300 feet above the sea. Nightingale Island differs from the other two as much in geological structure as in outward appearance. The principal island rises from the sea in low cliffs, nowhere on the eastern side exceeding 30 or 40 feet, and generally lower. At the south end the ground rises from these cliffs by several steep ascents to the peak 1105 feet high, which on its northern side presents a nearly perpendicular face of about half its height from the sea. The rest of the island is more undulating, the light grey rocks appearing only here and there through the openings in the long tussac grass. Of recent volcanic action there appears to be no trace. The shore cliffs consist of a conglomerate, or rather breccia, of generally light-coloured doleritic fragments in a white felspathic matrix. These are overlaid, in places, by a bed of old igneous rocks. The peak, which I did not reach, is composed of light grey subcolumnar rock. All along the top of the cliffs, and about 35 feet above the sea, an ancient beach is seen to run; and the huge caves, at a considerable height above high-water mark, afford additional evidence of the rising of the land. The middle island, which I explored, consisted entirely of the above-mentioned breccia, and even at its highest point (150 feet) it was much water-worn. Dykes are by no means so frequent in this as in the other islands. Where they occur penetrating the breccia, the latter appears to be rendered more easily decomposable, the result being that the dykes form the axes along which creeks or inlets indent the shore. In the island of Tristan, the gully behind the settlement, in the centre of which the spring rises which supplies the village brook, is formed in a similar way. It is backed by a vertical dyke (if a mass at least sixty yards wide can be called so) of rock similar to that observed on Nightingale, and, like it, it has altered the adjacent rock considerably; and, probably from the pressure of the sides during its injection, it has a most perfect, almost slaty cleavage, which renders it easily disintegrable, though it does not appear to decompose easily. Dykes of this description, but of usually not more than 1 or 2 feet in thickness, traverse the rocks, seen in section in the face of the cliff, both in Tristan and Inaccessible, in great numbers. Besides these, there are others of a very compact, fine-grained, basaltic rock intersecting the nearly horizontal layers, which form the cliff, in all directions, and showing very marked differences in texture at the sides, where the action on the contiguous rock is apparent. In one of the specimens collected the rock in the interior of the dyke is of the usual light colour, while the edge is marked by a black obsidian-like band of half an inch breadth, as sharply defined from the internal mass as if it had been painted.

The cliffs, being quite perpendicular and naked, give a good view of a vertical section of the island. At their base the rubbish fallen down from them has accumulated to a heap reaching sometimes quite 100 feet up the face. I had thus the opportunity of observing two sections of what had been valleys or hollows, but which were filled up with finely levigated volcanic material. From the arrangement of the material I should think that it had been erupted by a subaerial volcano and fallen into a bay, where it had gradually settled. If such has been the case, it furnishes additional evidence of the rising of the land in these parts.

During the cruise between the Cape of Good Hope and Melbourne three islands were landed on, namely, Marion, Kerguelen, and Heard islands. On the first of these a day was spent. The soft mossy nature of the ground made the walking very heavy, which, combined with the necessity of being at any time prepared to join the ship in case of change of weather, rendered any expedition far from the coast impossible. Viewed from the sea, the rocky shores are seen to be surmounted by an undulating country covered with herbage, which, as the height increases, passes into a barren mountain cluster with many sharp and sometimes perfectly conical peaks. The highest of these were covered with snow, and for the greater part of the day enveloped in mist; the lower ones were mostly of a bright brick-red colour. Where the coast cliffs could be viewed they showed layers of compact and brecciated lavas of no great thickness. Having landed at the mouth of a watercourse, I traversed the beach to the westward until I reached the next stream, which I followed some distance inland. When the swampy moss-covered ground, whose uniformly dull green colour was relieved here and there by the snowy plumage of the nesting albatross, had been left behind, the stream was found to flow over an apparently very recent stream of black cellular lava, whose ripples and eddies were still perfectly fresh, except in the very centre, where they had suffered some slight abrasion; of any hollowing action on the part of the water, however, there was no trace, the windings and little waterfalls being still determined by the original inequalities of the solidifying rock. The lava was basaltic, containing much olivine. Close by the bed of the stream rose several of the above-mentioned red conical hills. One of these, the highest within reach, and the only one I had time to ascend, consisted of a heap of loose scoriæ dipping away on all sides at a regular and very steep angle. Few of these pieces of scoriæ were more than six inches in diameter; and had it not been for the occasional clumps of moss, which alone afforded a sure footing, the ascent would have been a matter of considerable time. At the top was a perfectly conical pit, and slightly below the summit, on the north side, were three smaller and similar pits. The scoriæ of which the hill is made up consisted of a highly cellular red ground-mass, with indications of augite, without, however, any perfect crystals being discernible. Besides the red scoriæ, there were some of a chocolate-brown colour, with frothy exterior and compact kernel. The shape of some of them resembled the almond-shaped bombs found in many volcanic districts; but I did not notice any with the dense outside and highly cellular core so characteristic of the true volcanic bomb. Besides this hill there were five or six others precisely similar in appearance, and rising out of the same valley or depression in the ground. From the top of the hill this depression could be seen to be bounded, towards the interior, by a semicircular cliff of rock, in some parts columnar, and open towards the sea. Above this cliff rose the snow-covered cones and peaks of the interior, which, wherever the snow had been removed, showed the same red colour and steep sides, so that there can be little doubt of their being similarly formed to those on the lower ground. On leaving the stream-bed and returning to the eastward over the spur of the mountain, the above-mentioned cliff had to be skirted, and it was found to consist of a light grey compact doleritic rock.

From these few observations it may be concluded that the island consists of a foundation of older igneous rock ruptured and surmounted by recent volcanoes. That these have been active at no very ancient date is, I think, rendered probable by the perfect preservation of the forms of the cones with their summit craters, and by the fact that the mossy vegetation so luxuriant at their base, and retaining this luxuriance on the certainly older mountain-spurs to an elevation at least equal to that of the top of the cone ascended, has as yet spread up their sides only in straggling isolated patches.

The evidence afforded by the want of erosion deserves all the more weight when the position of the island is remembered, where, of necessity, the rainfall must be considerable.

The island of Kerguelen was visited at various points on the north-eastern and south-eastern coasts. The first part touched at was Christmas Harbour, already visited by Cook, Ross, and other navigators. It is a deep inlet surrounded by high rocky banks, which are in many places quite precipitous. At the head of the bay there is an extensive sandy beach; and the ground behind it slopes at a tolerably easy gradient up to the top of the ridge, which is occupied by a large lake. From a ship anchored in the harbour an excellent general view of the arrangement of the rocks can be obtained; they are seen to be arranged in apparently perfectly horizontal beds, the separation lines of the different beds being easily traced all round the harbour. Where the sides are not precipitous the summit of the ridge is attained by a series of terraces, and the summit of the ridge is, as might have been expected, almost perfectly flat. The continuity of the flat-topped surfaces, both of the northern and of the southern ridges, is broken by the two most conspicuous objects in the landscape, namely, Table Mountain on the north, and one unnamed on the south. This rock-mass does not project above the horizontal hill-top, but rather appears to stand out from it like a huge boulder. The summit of the ridge has been called Mount Havergal; but it is formed of the ordinary bedded rock, this "neck" of conglomerate not reaching any greater height than that of the contiguous parts of the ridge. These hills belong to a class representatives of which were found again in the south in Greenland Harbour; and as they resemble each other closely they will be described together. In both places they protrude through the horizontal beds of basalt, differing from these and from each other in nature, and without having caused any apparent disturbance in the arrangement of the beds which surround them. The horizontal beds which form the mass of the land are basaltic, and vary from 10 to 20 feet in thickness, being generally compact; but in ascending the hill beds are met with frequently which contain large amygdaloidal cavities filled with zeolites, principally analcite and heulandite. These minerals are very plentiful in this part of the island; and when rounded by the action of water, they form remarkable white pebbles on the otherwise dark-coloured volcanic sand. Up to the summit the alternation of beds of compact subcolumnar rock of amygdaloid is pretty regular. The amygdaloid is of two kinds; in one the cells are small, very thickly disseminated, and completely filled up by a zeolitic mineral; the other has larger cavities, less thickly spread, and generally only coated with crystals, while seams filled with crystalline matter are also frequently met with. The cavities contain generally analcite, the seams heulandite. The ridge on the southern side is higher than that on the northern; and from it, on a clear day, a very extensive view of the island towards the southward can be obtained. The coast on this side being much indented by fiord-like inlets, the horizontal bedding of the rocks in which they are enclosed can be distinguished, even at great distances, by the consequent terracing of the hill-sides, which is especially conspicuous on the shoulders and promontories. It is worthy of remark that, to the eye viewing as above, the heights of the ridges appear to differ very little from each other, the effect produced being that of a vast tableland quarried into deep indentations running down to the sea. Out of this plateau rise many peaks of considerable altitude, and often so sharp and steep in outline that at first I never doubted they were recent volcanic mountains. A nearer view of them, however, showed them generally to consist of the same horizontally bedded rock found underneath; and it was impossible to avoid the impression that they might be the remnants of a higher plateau, of which all but these peaks had been removed by the rodent action of ice, of which there is abundant evidence.

After leaving Christmas Harbour anchor was dropped in Betsy Cove, a small bay near the eastern end of the island. Here the hills have exactly the same structure as in the north, consisting of horizontal layers; but they are further removed from the sea, and from their base to Point Digby stretches an expanse of almost perfectly level plain, broken only by the remarkable Mount Campbell, which I regret I was not able to visit.

Prince of Wales's Foreland is an elevation formed by slender basaltic columns, many of which were clustered together into what, if perfect, would have formed spherical agglomerations. The basalt contained large cavities filled with olivine. Behind this rocky point the usual flat-topped range of hills stretches inland, which consists of the same basalt with much olivine, only not columnar, but in tabular masses with almost slaty cleavage.

Nearly opposite Prince of Wales's Foreland, and on the other side of the entrance to Royal Sound, is a very remarkable hill of a castellated appearance; it was called "Cat's ears." I believe it belongs to the same class of hills as Table Mountain in Christmas Harbour. The ruggedly worn rock at the crest, which gives it its castellated look, consists of a light-coloured ground, in which are enclosed pieces of the recent scoriaceous lava which occurs immediately beneath it and large crystals of augite. These crystals, though apparently perfect when imbedded in the rock, were not found otherwise than broken when weathered out; and in places inside these natural battlements, where there was free play for the usually boisterous wind, all the lighter sand had been blown away, leaving the ground covered by a jet-black gravel. Both these crystals and the rocks show the abrading effect of blown sand, the crystals having lost their regularity of form and the rocks having acquired a more definite shape than would have been the case had the weathering proceeded equally on all sides. Here, however, and still more remarkably so in Heard Island, the constant and violent westerly winds, wherever they have an opportunity of charging themselves with sand, sculpture the rocks into shapes of apparently unnatural regularity. From this hill another similar but smaller one could be seen close to the base of the "Sugar-loaf." It resembled more a circle of Druidical stones protruding through the moorland than a hill; my time, however, was too limited to admit of my visiting either it or the imposing Sugar-loaf, the structure of which appeared from a distance to be quite peculiar.

On entering Greenland Harbour, which at its head is only separated by a narrow neck of land from Royal Sound, the eye is at once struck by the strange protrusions of light grey rock through the ordinary horizontal basaltic beds which form the hill-ranges. The most extensive of them, which occurs on the summit of the range on the western side of the harbour, has at a distance a very strong resemblance to a ruined castle. I was able to examine two of them, one on the summit and one down nearer the landing-place, both on the west side of the harbour. The rock in both of them is identical, and consists of a light, greenish-white phonolite protruding through the horizontal beds of augitic rock. These cylindrical masses of phonolite are columnar at the outer edges, the columns lying horizontally and being arranged radially. This columnar structure, however, disappears a few feet from the outside, and the rock is simply massive. The effect of weathering has been to split it up into loose blocks, which lie thickly scattered over the ground enclosed. The whole outside line being constructed of horizontal columns, forms a sort of natural cyclopian wall, much more capable of resisting the degrading influence of the weather than the massive inside; hence we might expect that as they always protrude on a hill slope, the rock being disintegrated in the centre would slip down the hill, forming a heap or talus of rubbish below, and overwhelming the wall encircling the lower edge, but at the same time falling away from the wall of the upper edge, which, thanks to its artificial structure, is able to keep together its fragments; and, in fact, this is what we observe. The upper wall of the more distant one, which stands out a prominent object on the summit of the ridge, is over

50 feet high, and presents a perfectly smooth wall-face to the outside. As it stretches down the hill-slope, which here is very steep, its height diminishes irregularly until it is lost in the heap of loose stones which covers the lower wall and the whole inside.

The rock is hard and compact, of a light greenish grey colour, with much of the appearance, though none of the ring, of phonolite. Near the outside, or in the columnar part, the rock is closer-grained than in the centre, and has a distinct cleavage in a plane perpendicular to the length of the columns. It gelatinizes partially with hydrochloric acid, and the solution contains much soda and some sulphuric acid. It is therefore probable that both nepheline and nosean are present.

Another prominence on this side of the harbour is formed of precisely similar material. It is a round, greenish grey hill covered with phonolitic rock lying about in angular fragments, generally of a size to be easily lifted. The rock is very similar to that of the hills just described; and it seems to belong to the same class, differing from the others owing to the complete disappearance of the outside wall, large pieces of which lie scattered on the slope like portions of dislodged masonry.

It is to be remarked that in neither of these cases was there any distortion in the beds in which the phonolite occurred. The line of junction of the highest one with the augitic rock was very well shown, and I was enabled to get specimens from it. For some feet from the line of junction the basalt is considerably altered, the large crystals of augite and olivine disappearing as the line of junction is approached. This line is in general quite decided; there are many angular particles of the phonolite completely surrounded by the basalt, whereas basalt imbedded in phonolite was not observed. Further, the grain of this basalt, in immediate proximity to the junction, is very fine, becoming rapidly coarser till the basalt at 10 feet from the junction has the porphyritic appearance which it presents at other parts of the hill. These two facts appear to point to the phonolite as being the more ancient of the two, and to the basalt as having flowed round it. How the phonolite came to be sticking up in the pillar-like form which it must have had is very difficult to say; but the peak of Fernando Noronha, however it may have been formed, is always evidence of the possibility of such a thing. There is no necessity for supposing that the portions of these phonolitic masses which we see should be sections of cylinders: they may equally well be sections of domes. The other view that the phonolite had burst through the lava appears to me to be untenable in view of the facts above stated.

Of the similar hills in Christmas Harbour, Table Mountain consists of columnar basalt with large cavities filled with olivine. The columns starting normally to the cylindrical surface of the enclosing rock curve upwards, and, unlike the phonolite, are continued well into the mass of the hill. The top of this hill is covered with loose fragments of basaltic columns. I did not succeed in obtaining specimens from the junction of the columnar with the bedded rock; in fact there appeared to have been next to no fusion between the two.

The corresponding hill on the south side of the harbour is formed entirely of volcanic conglomerate, intersected here and there by dykes, some of which show on the outside the obsidian-like bands produced by rapid cooling, which were observed in considerable abundance at Tristan d'Acunha.

Fossil wood is found on the south side of Christmas Harbour imbedded in the igneous rock. It occurs in stumps and smaller branches. The colour varies from yellowish white to chocolate-brown and black. Its hardness is also very variable. Even in the perfectly white pieces there is still much organic matter remaining. The bark has been transformed into a brown crystalline mass of greasy appearance, which effervesces with acid. The inside of one rather large trunk, the core of which had probably rotted away, was entirely filled up with a mass of igneous rock with elongated cavities filled with crystals. Iron pyrites was occasionally observed. Parts that internally consisted of nothing but trap-rock often presented on the outside the fibrous appearance of the simply silicified wood; the thickness of this rind, however, was insignificant.

A species of brown coal occurs on the south side of Christmas Harbour between two layers of basalt, and only a few feet above the sea. It is, practically, of no use, being too poor to burn at all alone.

Near the eastern point of Howe Island much amygdaloid was found, the geodes here consisting almost exclusively of agate. The tops of the hills were thickly strewed with such as, in the lapse of time, had been weathered out of the matrix. Many of these presented a very striking appearance, one of the corners of the cast of the cavity having been neatly planed off, and in some instances even highly polished, in others covered with a natural etching of great beauty. The occurrence of these abraded faces is, I think, a further evidence of the recent prevalence of ice-action over the whole island; and it must be remembered that glaciers actually do reach the sea-level in fiords on the main island not more than twenty miles distant.

It is worthy of remark that, although amygdaloids are common along the north-eastern side of the island, the nature of the geodes is different in different localities. In Christmas Harbour they are almost exclusively zeolites; in Cumberland Bay those who have visited it report numerous cavities in the rock filled with quartz crystals, and, indeed, one of the promontories in it is called Crystal Point; while at Howe Island the silica with which the cavities were filled occurred entirely in compact masses of agate or chalcedony. The cavities were usually quite full, the geodes being solid and forming an accurate cast of the cavity. Where this was not the case the interior presented a finely mammillated surface. I did not observe quartz crystals either here or at Christmas Harbour; nor did I observe the zeolites, so common in the last-named locality, either at Howe Island or Betsy Cove.

Scoriæ were only met with on one occasion, namely, on the hill called "Cat's ears," at the entrance to Royal Sound; but, as far as could be decided by a view from the sea, they seemed to be by no means rare on the southern coast, where the cliffs, worn by the violence of the south-westerly gales, show sections of what undoubtedly is red scoriaceous matter. The whalers who frequent the harbours of the island chiefly for sealing purposes, and from whom much valuable and reliable information was obtained, affirmed the existence of an active volcano on the western side of the island, as well as of springs of mineral water, both hot and cold, and of petroleum.

It is much to be regretted that our time was too limited to allow of our visiting the but little-known coast of the western side of the island.

The group of Heard and M'Donald islands was visited after leaving Kerguelen. M'Donald, the smaller of the two, is, I believe, quite inaccessible. The ship anchored in Corinthian Bay, Heard Island, on the afternoon of the 6th February, when I had the opportunity of spending about an hour and a half on shore. The landing-place was at the head of the bay on a flat sandy beach at the mouth of a river which comes out of one of the magnificent glaciers which form a continuous ice-wall along the south-western shores of the bay. Like all glacier-streams it was very muddy. The island here is very narrow, not more than a mile broad, and the sandy plain stretches from sea to sea; it, in fact, forms the heads of three bays, namely, Corinthian bay facing to the north-east, the open sea towards the south-west, and a narrow bay which runs in between two remarkable promontories on the north-east. The connexion of these two promontories with the main island by means of this sandy plain is so low that a depression of a few feet would suffice to separate them from each other and from the mainland. The sand is very dark-coloured and highly magnetic, and was being blown with such violence by the then prevailing south-west wind, that it was necessary, when exposed to it, to use some protection for the face. Nowhere have I seen the abrading power of blown sand better exemplified than on the isolated rocks which have rolled down from the heights above and remained fixed in the sandy plain, exposed to the constant strong south-westerly gales, driving the sharp volcanic sand against their sides. In this way they have frequently been cut and dressed as by a mason's chisel. It is, however, not the south-westerly winds alone which produce this effect; but from their great predominance they have given the rocks the peculiar "sheared" appearance, much resembling that assumed by the trees growing on a coast exposed to the trade-winds. If favourably placed rocks be carefully examined, the effect of every prevalent wind will be observed in the facets which it has produced on the surface. The largest facet, and the one which determines the general appearance of the rock, is the one turned towards the west; and I do not doubt that the areas of the others would afford useful information as to the relative prevalence of other winds.

Of the promontories above mentioned, the one which extends towards the west is a lofty mountain rising precipitously from the sea on the N.E. and S.W., and terminating in two peaks. Between these two peaks a glacier descends to the edge of the cliff overhanging the sea on the north-east side, over which the ice-masses fall with a thundering noise. The other promontory or peninsula is covered by a flow of very recent lava, the eddies and ripples on the surface being still quite fresh. This stream of lava proceeds from the base of a recent but much dilapidated crater, which having sprung up close to the sea could only have been preserved by renewing its substance with constant eruption. When this ceased, the degrading action of the waves began to tell; and at present it is worn into a group of fantastic-looking peaks, the vertical sides of which are marked by the layers of scoriæ dipping away from the centre. The lava-stream covers the whole of the peninsula, and from having been worn by the waves it forms a range of low black cliffs along the north side of Corinthian Bay. In the face of these cliffs many large cavities, bubbles in the once molten lava, had been opened, and were tenanted by the nesting Cape pigeon.

The glaciers which cover the whole of the southern side of Corinthian Bay have been prevented from encroaching on the beach at the head of it by a sharp conical hill of scoriæ, behind which the ice-covering stretches from sea to sea.

H.M.S. 'Challenger,'
December, 1875.

[The Tables which accompany this paper are preserved for reference in the Society's Archives.—Sec. R.S.]

VII. "Report to the Hydrographer of the Admiralty on the Voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a Position in lat. 32° 24′ S., long. 13° 5′ W." By Prof. Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff on board. Received May 5, 1876. Read June 15.

[Plates 25-33.]

H.M.S. 'Challenger,'
Ascension, March 1876.

Sir,—I have the honour to report that we left Stanley Harbour in East-Falkland Island for Monte Video on the afternoon of the 6th of February, and on the 8th we sounded in lat. 48° 37′ S., long. 55° 17′ W., about 200 miles to the N.E. of Stanley, in a depth of 1035 fathoms. The trawl was lowered, but it was unfortunately carried away, after the weights, which were at a distance of 300 fathoms in advance of the trawl, had been brought in board. The rope looked much chafed, as if it had been ground against rocks. The sounding-machine brought up no sample of the bottom; but a tow-net attached to the dredge-rope at the weights contained a little gravel and one or two small organisms. The bottom-temperature was 1°·7 C.

The following day was fine, with light uncertain winds; on the 10th it was blowing half a gale and the sea was running too high for sounding-operations. On the 11th the weather was fine, the wind becoming more moderate towards noon; at 10 A.M. we sounded and put down the trawl in 2040 fathoms, with a bottom of bluish mud containing many *Globigerinæ*, and a bottom-temperature of +0°·3 C. The position of the sounding was lat. 42° 32′ S., long. 56° 27′ W., about 200 miles to the eastward of Valdes Peninsula. Temperature-soundings were taken down to 1500 fathoms (Curve 318, Plate 27). This sounding gives a singularly rapid fall from 14°·2 on the surface to 2° C. at 125 fathoms; the edge of the Antarctic indraught appeared to be pushed up against the American shore by the western border of the southern branch of the reflux of the equatorial current, as the Labrador current is banked up by its northern branch, the result being no doubt increased in both cases by the flinging up of the polar water against the western land-barrier on account of its low initial velocity.

On the 12th we sounded in 2425 fathoms, and took a series of temperatures; the upper temperatures were decidedly higher than they were the day before, 5° occurring at 125 fathoms, 2°·5 at 700, and 2° C. at 1100 fathoms. The position of the sounding was lat. 41° 54′ S., long. 54° 46′ W.: it was nearly double the distance of the previous sounding from the 100-fathom line, which here nearly corresponds with a steep submarine cliff of great height. The bottom-temperature was −0°·4 C. (Curve 319, Plate 27). On the 14th we sounded in 600 fathoms on the plateau extending from the South-American coast, opposite the estuary of the River Plate, 144 miles from Lobos Island. We took a set of temperatures to the bottom, and found the gradation, so far as it went, much the same as the day before; the bottom-temperature was 2°·7 C. On this occasion the trawl was most successful, and gave us a very fair idea of the fauna of moderate depths along the coast; probably not fewer than sixty species of different groups were recovered, including a very handsome *Pennatula* between two and three feet in height, some deep-sea corals of very special interest, which are being worked up by Mr. Moseley, and some fine Echinoderms and sponges. On the 15th we anchored in Monte-Video Roads.

We left the anchorage at Monte Video at daybreak on the 25th of February, and after swinging ship for errors of the compasses, we proceeded down the estuary. In the afternoon the trawl was put down in thirteen fathoms to get an idea of the fauna of the brackish water. The species procured were comparatively few: but among them was a plentiful supply of an interesting Alcyonarian Cœlenterate of the genus *Renilla*, which was new to us. On the two following days we crossed the shallow-water plateau, and on the 28th we sounded and trawled in 1900 fathoms over the ledge. A serial temperature-sounding gave a bottom-temperature of 0°·0 C., 1°·0 at 1725 fathoms, 3°·0 at 600 fathoms, and 20° at 50 fathoms (Curve 323, Plate 29). The trawl was not very successful, but it brought up a few things of some interest; among them an example of a small sea-urchin, of which we had previously taken single specimens at widely distant stations, off the coast of Nova Scotia, near Gomera Island, near New Zealand, and near Japan. The bottom was chiefly river-mud with very little carbonate of lime.

On the following day we sounded in 2800 fathoms, and again lowered the trawl. The bottom was a greyish mud, with little or no carbonate of lime, and the bottom-temperature was −0°·4 C. The trawl-line parted near the ship in heaving in.

On the 1st of March we proceeded on our course, and on the 2nd we sounded in 2650 fathoms, with a bottom of grey mud and a bottom-temperature of 0°·4 C. The trawl was put over, and a series of temperature observations was taken to 1500 fathoms. (Curve No. 325, Plate 29.) This sounding is very instructive; the isothermobath of 3° C. is found at 600 fathoms, so that we have a mass of water at a lower temperature 2000 fathoms in thickness; 2°·5 C. occurs at 1900 fathoms, and zero at 2400. The very marked hump of the curve extending from a depth of 125 fathoms to a depth of 255, and corresponding with the wide spaces between the isothermobaths of 15° C. and 6° C. on Plate 28, evidently indicates the position and volume of the Brazil current, the southern deflection of the equatorial current after its bifurcation at Cape St. Roque. The trawl came up containing an unusually large number of organisms for this depth, including two specimens of an undescribed species of *Euplectella*, some corals, several Echinoderms illustrating three of the orders, some beautiful examples of a species of *Stylifer* commensal on one of the Holothurians, and several fishes.

Next day we sounded in 2775 fathoms, and took temperature-soundings. This series (Curve 326, Plate 29) presented a marked difference from that of the previous day. All the lines from that of 1°·5 C. had risen most palpably, most of them between 100 and 200 fathoms. Even the surface participated in the fall of temperature, having sunk from 21°·6 C. to 19°·9. This is evidently a space in the Brazil current occupied by colder water, like the peculiar cold interdigitations which are so marked in the Gulf-stream. The position of this sounding was lat. 37° 3′ S., long. 44° 17′ W. A serial temperature-sounding on the following day, at a distance of 80 miles to the eastward, where the depth was 2900 fathoms and the bottom-temperature −0°·3 C., showed by the sinking of all the isothermobaths that we had again entered the normal flow of the Brazil current.

On the 6th of March it was blowing hard from the S.W. with a heavy sea. We sounded in 2900 fathoms, with a bottom of grey mud and a bottom-temperature of $-0^{\circ}{\cdot}3$ C.; but the weather was too boisterous to admit of a serial temperature-sounding. On the 7th the sea was more moderate, and we sounded in 2375 fathoms, with a bottom-temperature of $-0^{\circ}{\cdot}6$ C., and took the temperature series represented by Curve 329 (Plate 30). The bottom was again a very fine grey or slightly reddish mud, almost free from calcic carbonate; samples of water were obtained for specific-gravity determinations and analysis down to 2000 fathoms.

On the 8th of March we sounded in 2440 fathoms, with a bottom of light red mud, and a bottom-temperature of $-0^{\circ}{\cdot}3$C.; and on the 9th, somewhat to our surprise, we sounded in 1715 fathoms, with a bottom of "*Globigerina*-ooze" and a temperature of $1^{\circ}{\cdot}3$ C. The sea was heavy, and trawling-operations were consequently rather difficult; the trawl was lowered, however, on account of the remarkable shallowness of the sounding; but it unfortunately came up foul, and the observation was lost.

It seems that this sounding was on the central meridional rise which separates the western from the eastern trough of the Atlantic at a depth apparently nowhere much beyond 2000 fathoms, near its western edge. As usual, the lower isothermobathic lines showed a tendency to rise slightly in the shallower water.

On the 10th the morning was misty and raining, with the wind northerly, shifting to the southward towards noon. We sounded in 2200 fathoms, "*Globigerina*-ooze," with a bottom-temperature of $+0^{\circ}{\cdot}4$ C. The trawl was put over; but on being recovered, it was found to have been down on its back, and it contained only a few fragments of one or two sponges, Crustaceans, and Echinoderms.

We ran on during the 11th and 12th, and on the 13th we sounded on "*Globigerina*-ooze" at a depth of 2025 fathoms, with a bottom-temperature of $1^{\circ}{\cdot}2$ C. The trawl again came up empty and reversed, some fragments adhering to the net, showing that there was a varied fauna, and that much interesting material must have been got from a successful haul.

The position of the sounding on the 14th was lat. 35° 45′ S., long. 18° 3′ W.; the depth was 1915 fathoms, the bottom "*Globigerina*-ooze," and the bottom-temperature $1^{\circ}{\cdot}5$ C., the distance from Tristan d'Acunha 310 miles. The trawl came up again foul, with only some fragments to indicate the presence of an abundant fauna. As we had already crossed our outward track in 1873, and as the temperatures at depths uninfluenced by the changes of the seasons seemed to verify in every way our former work, we thought it unnecessary to go further to the eastward on the direct line, and we took a north-easterly course towards a point in the meridian of the Island of Ascension, which was distant from us about 1685 miles.

We ran on next day, and on the 16th the position of the ship was lat. 32° 24′ S., long. 13° 5′ W., 1470 miles almost due south of Ascension, and 280 miles north by west of Tristan d'Acunha.

We sounded in 1425 fathoms on "*Globigerina*-ooze," with a bottom-temperature of 2°·3 C. The trawl had failed so frequently of late, that we determined to send down instead a large light dredge, which we had had made at Hong-Kong for the shallow-water sponge-producing seas of the Philippines. It came up with scarcely any ooze, and with only a small number of animal species; but among them were many very perfect specimens of the rare little sea-urchin, *Salenia varispina.* It is singular that although there were a large number of hempen tangles attached to the dredge, and they seemed to have done their work well, none of the Bryozoa so characteristic of moderate depths, with a bottom of "*Globigerina-ooze*," in the Atlantic were taken on this occasion. In the evening we made sail due north.

This portion of the voyage divides itself into two parts with very different conditions—the nearly meridional passage from the Falkland Islands to Monte Video, a distance of 1100 miles; and the line from Monte Video to Station 335, a little to the south of the parallel of 35° S. for a distance of 2100 miles.

Between Stanley and Monte Video four observing-stations were established, numbered on the charts and diagrams from 317 to 320. Two of these were in comparatively shallow water near the edge of, but still upon, the plateau which extends from the coast of South America to a distance of nearly 400 miles, and includes the Falkland Islands; the two remaining soundings, 318 and 319, were well beyond the cliff of the plateau at depths greater than 2000 fathoms. The shallow-water soundings were upon hard ground; in the two others the bottom was a greyish mud, to a great extent composed of land detritus. All these soundings, the two deep ones particularly, indicate the presence of a great underlying mass of cold water, the isothermobath of 2° C. occurring at Station 318 at a depth of 125 fathoms. At Station 319 the 2°-C. line is at 1100 fathoms, and the other isothermobaths up to 5° C. show a corresponding rise. I attribute this remarkable difference between two soundings so near one another to the banking of the cold water against the submarine cliff by the Brazil current; sounding 118 seems to have fallen directly upon the "cold wall."

At the deeper sounding (319) the thermometer fell, for the first time in our experience in the South Atlantic, below the freezing-point; but the relations of this very low bottom-temperature will be better understood when we come to consider the section between Monte Video and Tristan d'Acunha.

On the line between Monte Video and Station 335, fifteen observing-stations were established. The first three of these, 321 to 323, were on the estuary of the River Plate, or (323) just beyond the edge of the delta at its mouth; the next seven, 324 to 330, gave a section of a wide inlet into the western trough of the South Atlantic with a mean depth of 2750 fathoms; and the remaining five stations, 331 to 335, were on the central rise, with an average depth of 1850 fathoms. The mean bottom-temperature of the seven deep soundings is −0°·4 C., and that of the five soundings on the rise 1°·3 C.; the isothermobath of 0°·0 C. is at a depth averaging 2400 fathoms, a depth which it never much exceeds except where the cold water rises against the American coast, as at Stations 319 and 323; it therefore occurs in the line of the seven deep soundings only; and there it forms the upper limit of a mass of water with a temperature below zero, 320 square miles in section. Perhaps the isothermobath of 1°·5 C. may fairly be taken as the upper limit of the very cold water; the section of the Antarctic indraught below that temperature is here about 800 square miles. (The transverse section of the Gulf-stream is about 6 square miles; there is no volume of water at all in the Labrador current below 1°·5 C. opposite Halifax, that temperature being only found at the bottom.)

The isothermobaths of 2°, 2°·5, 3°, and 4° C. are very constant at 1500, 900, 600, and 400 fathoms respectively for all the stations on the parallel except Station 323 on the "cold wall," where all the lower temperature-lines are at a much higher level, and at the shallow sounding at Station 331, where all the lines below that of 4° C. rise slightly. We must be careful, however, not to attach too much importance to slight deviations of the colder lines. On the scale used in Plates 26, 28, 32, and 33, the mean interval between the isothermobaths of 2° and 3° C. in the Atlantic is 1000 fathoms; so that a rise or fall of 100 fathoms, which is very prominent on such diagrams, actually represents only one tenth of a Centigrade degree, an amount very small in itself, and, it must be remembered, entirely within the limit of error of observation with a deep-sea thermometer; it is only where there is a concordance among several lines in such a rise or fall that the indication is of any real value.

The mean temperature of the surface of the water at the anchorage at Monte Video was 22°·5 C.; at Station 320, just before entering the estuary, it was 19°·7 C.; at Station 323, on the edge of the plateau, it rose to 23°; and a temperature of 20° C. or a little above it was maintained up to Station 328, except at Station 326, which I have already referred to as occupying a cold space. After reaching Station 328 the temperature began to sink, and only recovered its former height when we moved northwards.

The curves deduced from the serial temperature-soundings along this line are represented in groups of four on Plates 29, 30, & 31. At Station 323 the temperature of the water fell rapidly and tolerably evenly, with only a slight prominence between 150 and 250 fathoms, to 5° C. at 350 fathoms; it then took a slower, but still a symmetrical sweep down to zero at 1900 fathoms. At Stations 324 and 325 the lines fell, with still only a slight protuberance in the same position as before, to 3° C. at 600 fathoms, when they sank very slowly to 1° C. at 2000 fathoms, and then again a little more rapidly to −0°·4 at the bottom. At the next Station (326) all the upper temperatures were remarkably low, corresponding with the cold "interdigitation" in the Brazil current. Stations 328 and 329 repeat Stations 324 and 325 with little variation; at the three Stations 330, 331, and 332 there was a most marked hump on the curves, occupying roughly the space between 150 and 250 fathoms; and at the three succeeding stations, 333, 334, aud 335, the hump wore out and finally disappeared.

The high surface-temperatures between the mouth of the River Plate and Station 328 are doubtless due to solar radiation (early autumn temperature) *plus* the additional warmth of the Brazil current, which is logged from the 29th of February to the 10th of March as running in a generally southerly direction at an average rate of 20 miles a day. The rapid fall for the first 150 fathoms represents mainly the loss of the heat due to direct radiation, which does not affect the curve to a depth much greater than 100 fathoms; and the hump from 150 to 250 fathoms represents the extra effect of the current, which appears to have there an average depth of 250 fathoms; it seems, however, not to be very constant, either in volume, direction, or rate.

To recapitulate briefly the more important points with regard to the distribution of temperature:—

1. The section between Monte Video and the meridian of Tristan d'Acunha includes, besides the soundings on the South-American plateau and the sounding on the "cold wall," a series of soundings in a western trough with an average depth of 2750 fathoms and an average bottom-temperature of −0°·4 C.; and a series of soundings on the middle bank of the Atlantic, with an average depth of 1850 fathoms and a mean bottom-temperature of 1°·3 C.

2. In the trough a huge mass of Antarctic water at temperatures ranging from 1°·5 C. to −0°·6 C. is creeping northwards at depths greater than 1800 fathoms; on the rise very little water at a lower temperature than 1°·5 C. passes northward; but that is only on account of the absence of the required depth, for the isothermobaths of 1°·5 and 2° C. are practically at the same level over the central plateau and over the trough.

3. On the surface a warm current, perhaps about 800 miles wide, and affecting the temperature of the water to a depth of 250 fathoms, continuous to the northward with the southerly deflection of a part of the equatorial current, passes to the southward, taking a slightly easterly direction on account of its higher initial velocity.

4. As a rule, the temperature falls rapidly throughout the section to a temperature of 3° C. at 600 fathoms, and then extremely slowly to the bottom.

We had always attached special importance to the temperature-soundings on this section, for we had expected them to throw some additional light upon the observations taken in the West Atlantic in the year 1873. These seemed at first sight to present certain anomalies; thus in our somewhat hurried run from Bahia to Tristan d'Acunha, we appeared to have missed the source of supply of water at an unusually low temperature which we found near the island of Fernando Noronha. The result has fully justified our anticipations.

Diagram A, Plate 32, represents the vertical distribution of temperature at Station 112, lat. 3° 33′ S., long. 32° 16′ W., 21 miles to the N.E. of Fernando Noronha. Diagram B gives the temperatures at Station 129, lat. 20° 12′ S., long. 35° 19′ W., nearly halfway between A and C, which represents the distribution of temperature at Station 327, one of the most characteristic in the section at present under consideration. The depth at Station 327 is 2900 fathoms, and the depths at the two other stations 2150 and 2200 respectively; and it will be seen that at the latter stations the bottom-temperatures correspond almost precisely with the temperature at Station 327 at like depths. The isothermobath of 2° C. is at the same height, 1500 fathoms, at the two southern stations; and at the northern station only, near the equator, it sinks to 1800 fathoms. The isothermobaths of 2°·5 and 3° C. correspond almost exactly in level at Stations B and C; at Station A all the isothermobathic lines under that of 4° C. down to the line of 1° C. are much lower than at Stations B and C; that is to say, that at the equator between 4° C. and 1° C. the water is considerably warmer than it is further south. The isothermobathic lines of 4° and 5° C. seem everywhere in the Atlantic to mark broadly the line of demarcation between the upper zone, where the temperatures are obviously affected by the diffusion of water by wind-currents, and the lower zone, where the temperatures are continuous with those of the Southern Sea. In the North Atlantic they are markedly lower than they are to the south of the equator; that is to say, there is a much larger body of water above them heated by conduction, convection, and mixture.

I have given in Plate 33 a general diagrammatic scheme of the vertical distribution of temperature in the western trough of the Atlantic, constructed from our serial temperature-soundings in the years 1873 and 1876. The diagram extends from lat. 42° S. to lat. 42° N., and includes as its southern limit the banking up of the Antarctic indraught against the South-American coast, and as its northern the "cold wall" of the Labrador current. This Plate seems scarcely to require much comment; but there are one or two points to which I would wish to direct attention.

At Station 327, so often referred to as a typical sounding on our present line, there is a mass of water 400 fathoms thick at a temperature below zero. Station 131, 600 miles south of Martin Vas, is on the edge of the central plateau, with a depth of 2275 fathoms and a bottom-temperature of 0°·7 C.; the deep passage therefore probably lies, if it have not already come to an end, between long. 28°·9 W. and the coast of America.

The distribution of the lower temperatures is much the same at station 131 as it is at station 327, the isothermobaths sinking slightly. At station 129, which is right in the middle of what may be supposed to be the direction of the current, the depth is 2150 fathoms, and the temperature 0·6 C.; the cold-water trough has therefore probably stopped before reaching this point; all the belts of water at given low temperatures are evidently continuous, although the isothermobaths of 3° C. and 2°·5 C. are now sinking rapidly. The accumulation of water above 3° C. in temperature is still more apparent at Station 112, nearly under the equator.

The next station, No. 15, is the first of a series of rather deep soundings taken after crossing the "Dolphin Rise" (the central bank of the Atlantic) on our voyage from Teneriffe to Sombrero in 1873. The deepest of these soundings are a little above 3000 fathoms; and they look from their position very much as if they were in the axis of the Antarctic indraught; but the temperature in no case falls below 1°·3 C.; and, tracing southwards, we find that a belt of shallow soundings (not more than 2000 fathoms) extends from the central plateau about lat. 21° N., long. 46° 30′ W., to the coast of South America, somewhere about Cape Orange. Going northwards, we encounter much greater depths, but no temperatures lower than 1°·3 C.; the whole mass of water to the very bottom rises steadily, though only slightly, to the northward, the merely local depression, which never reaches 1°·3 C. along the line of the Labrador current, being scarcely worth mention. It is evident that the water of the Atlantic is not generally affected by an indraught from the Arctic Sea. The diagram (Plate 33) shows very well the effect on the relative positions of the isothermobathic lines of the rapid removal of the warm surface-water over the region of the equatorial current and counter-current in the gathering up of the higher lines near the equator, and of the curl of the warm water to the north and south as the Gulf-stream and the Brazil current after the bifurcation of the equatorial current, in the depression of the isothermobaths of 20°, 15°, and 10° C. to the north and south of the equatorial region.

The causes of the very perceptible rise in temperature of the whole mass of the water of the North Atlantic will require further investigation. As I have said elsewhere, I am inclined to attribute it mainly to the banking in and accumulation of the northern reflux of the equatorial current, and its gradual mixture with the water beneath; and it seems to me that this cause is adequate to the effect. Still, even if this be so, we have to discover how that mixture takes place; and as there appears reason to believe that evaporation is in excess of precipitation in the Atlantic, it seems almost certain that differences in specific gravity and other causes come into play, though not very obviously. It is most probably a phenomenon of considerable complexity.

I will not refer to the thermal conditions of the eastern trough of the Atlantic at present; they are somewhat different, and will require separate illustrations after we have recrossed the basin, which we hope to do in the next six weeks.

To recapitulate the general facts and conclusions with regard to the distribution of ocean temperatures in the western trough of the Atlantic, it seems to me:—

1. That this trough (and the Atlantic as a whole) must be regarded in the light of an inlet or gulf of the general ocean of the "water hemisphere," opening directly from the "Southern Sea."

2. That the water of the Southern Sea simply wells up into the Atlantic, and that all the temperature bands of the Western Atlantic are essentially continuous with like temperature bands in the Southern Sea, with these modifications:—that (*a*) above a certain line, which may be roughly represented by the isothermobathic lines of 5° and 4° C., the temperature of the water is manifestly affected by direct radiation and by the very complicated effects, direct and indirect, of wind-currents; and (*b*) that the whole mass of under-water gradually and uniformly rises in temperature towards the head of the gulf.

3. That water at any given temperature (below 4° C.) can only occur in the Atlantic where there is a direct communication with the zone of water at the same temperature in the Southern Sea without the intervention of any continuous barrier. (The actual result of the present arrangement of such barriers is, that, however great the depth may be, no water at a temperature lower than 1°·3 is found to the north of the equator, and no water below the freezing-point in any part of the trough except in the depression already described between the mouth of the River Plate and Tristan d'Acunha.)

4. That the water of the Atlantic is not sensibly affected in temperature by any cold indraught from the Arctic Sea. (I purposely neglect the Labrador current and the small branch of the Spitzbergen current; for these certainly do not sensibly affect the general temperatures of the North Atlantic.)

5. That although there is a considerable flow of surface-water through the influence of wind-currents from the Atlantic into the Southern Sea, that flow does not seem to be sufficient to balance the influx into the basin of the Atlantic (the constant influx being proved by the maintenance of a general uniformity in the course of the isothermobathic lines, and by the maintenance in all the secondary basins of the minimum temperature due to the height of their respective barriers): that for several reasons (the lower barometric pressure and the supposed greater amount of rainfall in the Southern Sea, the higher specific gravity at the surface than at greater

depths in the Atlantic, the higher specific gravity of the surface-water in the Atlantic to the north than to the south of the equator), it is probable that the general circulation is kept up chiefly by an excess of evaporation in the region of the North Atlantic, balancing a corresponding excess of precipitation over evaporation in the water hemisphere.

Determinations of the specific gravity of the surface-water have been made daily. The mean of these for the section between Stations 323 and 335, the temperature reduced to 15°·56 C., is 1·02620. Of the eighteen days occupied in running the section nine were dry and fine, and on nine rain fell either continuously or in showers. The mean for the nine dry days is 1·02639, and for the nine wet days 1·02591. The maximum surface specific gravity for the section (1·02680) was at Station 323, at the point where probably the Brazil current has most effect on the surface, and the minimum (1·02494) was at Station 326 after a heavy fall of rain. The mean specific gravity of the surface-water at the temperature at which it was procured was 1·02502.

The specific gravity of the bottom-water was determined at ten stations on the section. Reduced to a temperature of 15°·56 C., the mean was 1·02601; the maximum, 1·02650, was at Station 323 at a depth of 1900 fathoms; and the minimum, 1·02580, was at Station 326 at 2775 fathoms. The mean specific gravity of the bottom-water at the depth at which it was procured was 1·02811, showing a difference between the two means of 0·00210, due to difference of temperature alone.

It seems from these observations that the differences of surface specific gravity due to differences of salinity along the section are very small, and that, with the exception possibly of station 323, which is abnormal in many respects, they depend mainly on the rainfall.

The difference between the mean surface specific gravity, the temperature reduced to 15°·56 C., and the mean bottom specific gravity under the same conditions is also very slight; the actual specific gravity at every point is practically determined by the temperature; and consequently the bands of equal density are, like the bands of equal temperature, virtually continuous with those of the Southern Sea.

There seems to be little doubt that the specific gravity of the surface-water is considerably higher in the North Atlantic than it is on the present section. On one section between Teneriffe and Sombrero, in 1873, Mr. Buchanan found the mean specific gravity at the surface (the temperature reduced to 15°·56 C.) to be nearly 1·02760; from the surface it fell rapidly to 1·0260, at a depth of about 600 fathoms, after which it remained nearly the same to the bottom.

Throughout the whole of this section the trawling-operations have been singularly unsuccessful. Out of ten trials in depths over 1000 fathoms only four produced any thing like satisfactory results; and this was the more unaccountable, as the comparatively moderate depths of most of them were such as usually to make the process almost certain.

In many cases, however, even when the line parted or the trawl came up foul, fragments sufficient were preserved to show that the fauna of the region was by no means deficient.

The first successful trawl was at a depth of 600 fathoms, on the edge of the South-American plateau. As at most places where we have had a fair opportunity of working at such depths, the number of species procured was very large. Sponges were abundant, including a large number of corticate forms, and several specimens of a species of the fine hexactinellid genus *Rossella*, identical with or very closely allied to *R. antarctica*, so common at Kerguelen. I have already referred to the large Pennatulids and to the remarkable corals belonging to the family *Stylasteridæ*, a group which Mr. Moseley, in an important paper which I beg to submit along with this, has determined to belong, with the *Milleporidæ*, to the HYDROZOA, and not to the ANTHOZOA, as previously supposed.

All the orders of Echinodermata were well represented. Bryozoa were abundant, and included fine masses of *Tubulipora*, *Idmonea*, and *Cellepora*, such as are found in like depths off the west coast of Ireland. Numerous crustaceans occurred, among them large species of *Arcturus*, of *Gammarus*, and of other genera, recalling the northern crustaceous fauna, along with species of *Serolis* and markedly southern Schizopods. Mollusca were, as usual, few; there were two or three fishes of deep-water types.

The next trawling-station was on the 28th of February in 1900 fathoms (No. 323); the number of species was not so great as on the previous occasion, but the different groups were fairly represented. We got here a single stem only of *Rhizocrinus lofotensis*, one of the rare crinoids belonging to the Apiocrinidæ. We have been unfortunate in never having found perfect specimens of this pretty little species, although fragments have come up frequently at widely separated stations.

Bryozoa were abundant, of more characteristic deep-water types than on the last occasion. There were two species of deep-water fishes belonging to the Macruridæ. At Station 325 the depth was 2650 fathoms, and the number of species procured was, as I have already mentioned, unusually large for so great a depth. The assembly of forms was of the usual deep-sea character. There were a considerable number of species of *Fungia symmetrica*, a generally distributed deep-sea coral; and the specimens at this station were of a much larger size than we had previously met with. There were many Echinoderms, including several species of a singular group of Holothuridæ, allied in some respects to *Psolus*, which we find widely distributed at great depths; they are principally characterized by an almost continuous calcareous plating, which runs out over long, tubular, spine-like appendages.

The next three trawlings were unsuccessful; and at Station 335, on the 16th of March, we determined to try a large light dredge. This was dragged along the bottom freely for a considerable distance; and although the number of species procured was small, we thought ourselves fortunate in securing fine examples of *Cidaris varispina*.

The following Table gives the general distribution of the principal animal groups at the different stations between the Falkland Islands and Tristan d'Acunha:—

	Station 317. 1035 fms.	Station 318. 2040 fms.	Station 320. 600 fms.	Station 321. 13 fms.	Station 322. 21 fms.	Station 323. 1900 fms.	Station 325. 2650 fms.	Station 331. 1715 fms.	Station 332. 2200 fms.	Station 333. 2025 fms.	Station 334. 1915 fms.	Station 335. 1425 fms.
Pisces.................	...	*	*	*	*	*	*	...	*	...	...	*
Cephalopoda..........	...	...	*	*	...	...	...	...	...	*		
Gasteropoda	...	...	*	*	...	*	*	...	...	...	...	*
Lamellibranchiata .	*	...	*	*	*	...	*	...	...	...	...	*
Brachiopoda	...	...	*									
Tunicata	...	...	*									
Pycnogonidæ	...	...	*									
Decapoda	...	*	*	*	...	*	*	*	...	...	...	*
Schizopoda	...	...	*	...	...	...	*	...	*			
Stomatopoda.												
Edriophthalmata ...	...	...	*	*	...	...	...	...	...	...	*	
Phyllopoda.												
Ostracoda.												
Copepoda.												
Cirripedia	*	...	*	...	...	*	...	...	...	...	...	*
Annelida	...	...	*	*	*	*	*	...	...	*	...	*
Gephyrea.												
Bryozoa...............	...	...	*	...	...	*	*	...	*	*		
Holothuroidea	...	...	*	...	...	*	*					
Echinoidea	...	...	*	...	...	*	...	...	...	...	*	*
Ophiuridea	...	...	*	...	...	*	*	...	*	*		
Asteridea	...	...	*	...	...	*	*	...	...	...	...	*
Crinoidea	...	...	*	...	...	*						
Hydromedusæ	...	...	*	...	...	*	...	...	...	...	...	*
Zoantharia	...	...	*	*	...	*	*	...	*	...	...	*
Alcyonaria............	...	...	*	*	...	...	...	...	...	*		
Porifera..............	*	...	*	...	...	*	*	...	*	*	*	
Rhizopoda............	...	...	*	...	...	*	*	...	*	*	*	

Note.—At Station 317 the trawl carried away, and the few specimens came up in a tow-net attached to the trawl-rope. At Station 318 the trawl did not reach the bottom. At Stations 331, 332, 333, and 334 the trawl came up foul, and fragments of animals only were got adhering to the net. At Station 235 a large dredge was used.

It has not of course been possible to determine the species in detail; but the general characteristic of the fauna throughout the section is much the same as we have found almost invariably at like depths in temperate regions. The general assemblage certainly tends to confirm me in the opinion that the distribution of the deep-sea fauna mainly sets from the Southern Sea into the Atlantic.

I beg leave to report that the departments under my charge are in a satisfactory condition. I hope to have an opportunity of sending from

St. Vincent some notes of the general results of our observations on the physical and biological conditions of the eastern trough of the Atlantic.

I have the honour to be, Sir,
Your obedient Servant,
C. Wyville Thomson,
Director of the Civilian
Scientific Staff on board.

Captain Evans, C.B., V.P.R.S.

DESCRIPTION OF THE PLATES.

Plate 25.

Track of the ship from Stanley Harbour, East-Falkland Island, to Station 335, lat. 32° 24′ S., long. 13° 5′ W., in the meridian of the Island of Ascension.

Plate 26.

Diagram showing the vertical distribution of temperature between the Falkland Islands and Monte Video.

Plate 27.

Curves constructed from the serial temperature-soundings at Stations 317, 318, 319, and 320 between the Falkland Islands and Monte Video.

Plate 28.

Diagram showing the vertical distribution of temperature between Monte Video and Station 335.

Plate 29.

Curves constructed from the serial soundings at Stations 323, 324, 325, and 326.

Plate 30.

Curves constructed from the serial soundings at Stations 327, 329, 330, and 331.

Plate 31.

Curves constructed from the serial soundings at Stations 332, 333, 334, and 335.

Plate 32.

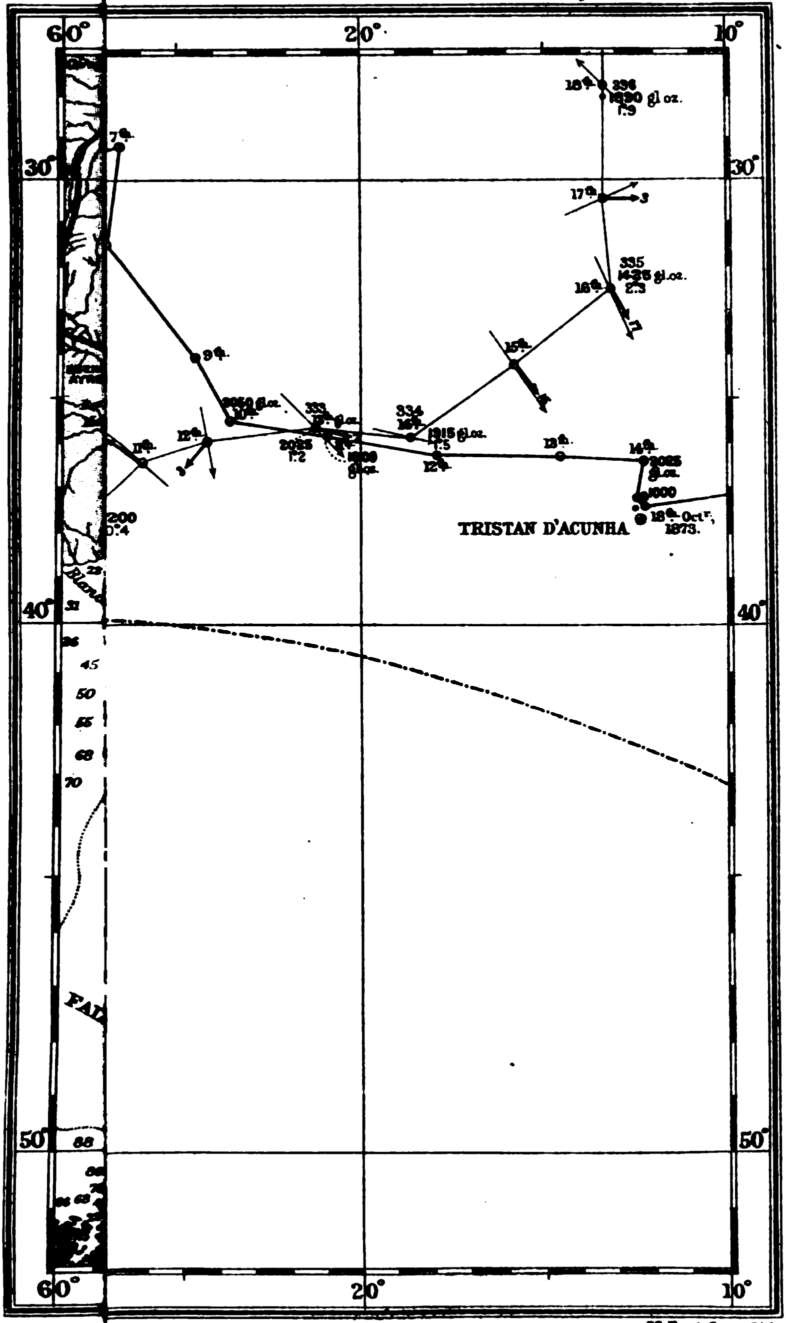
Diagram showing the vertical distribution of temperature at Stations:—

A. No. 112. Sept. 1st, 1873, lat. 3° 33′ S., long. 32° 16′ W.
B. No. 129. Sept. 30th, 1873, lat. 20° 12′ S., long. 35° 19′ W.
C. No. 327. March 4th, 1876, lat. 36° 48′ S., long. 42° 45′ W.

Plate 33.

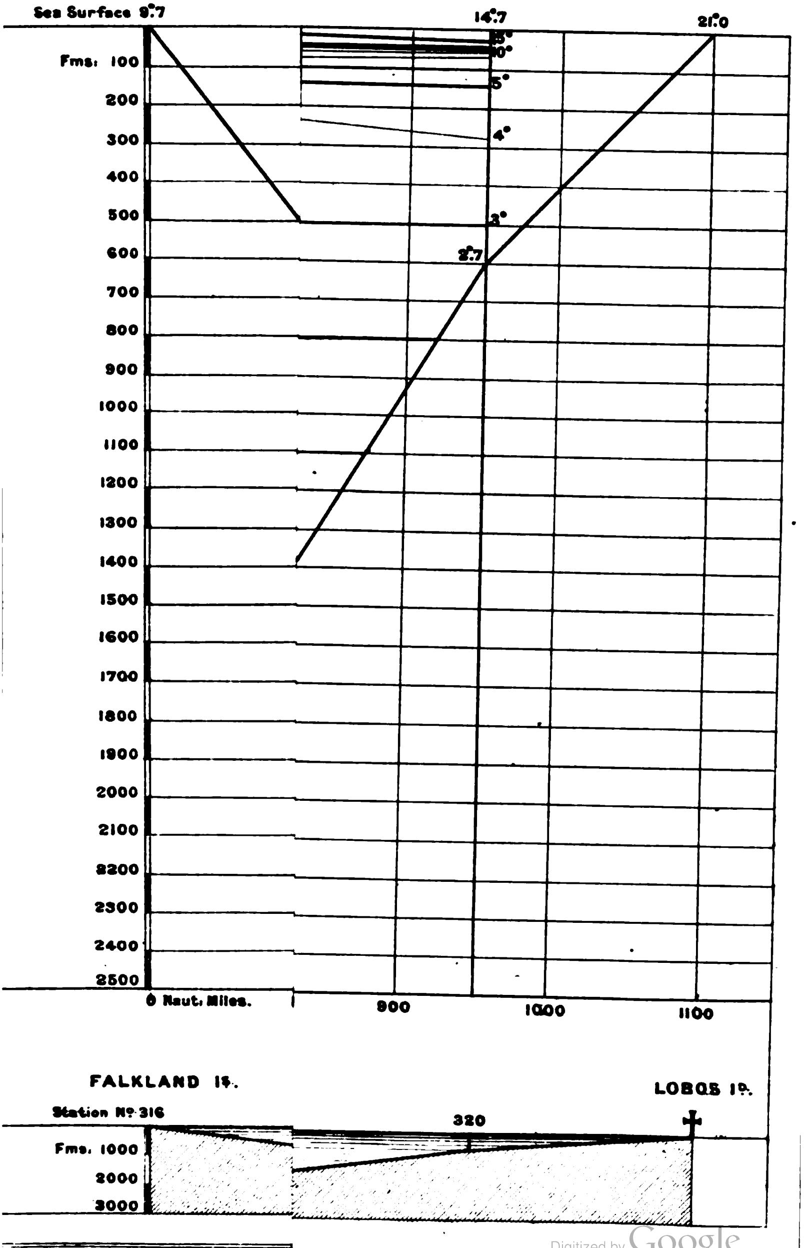
Diagram showing the vertical distribution of temperature, as far as possible, in the axis of the western trough of the Atlantic, from lat. 42° S. to lat. 42° N.

Proc. Roy. Soc. Vol. 24, Pl. 25.

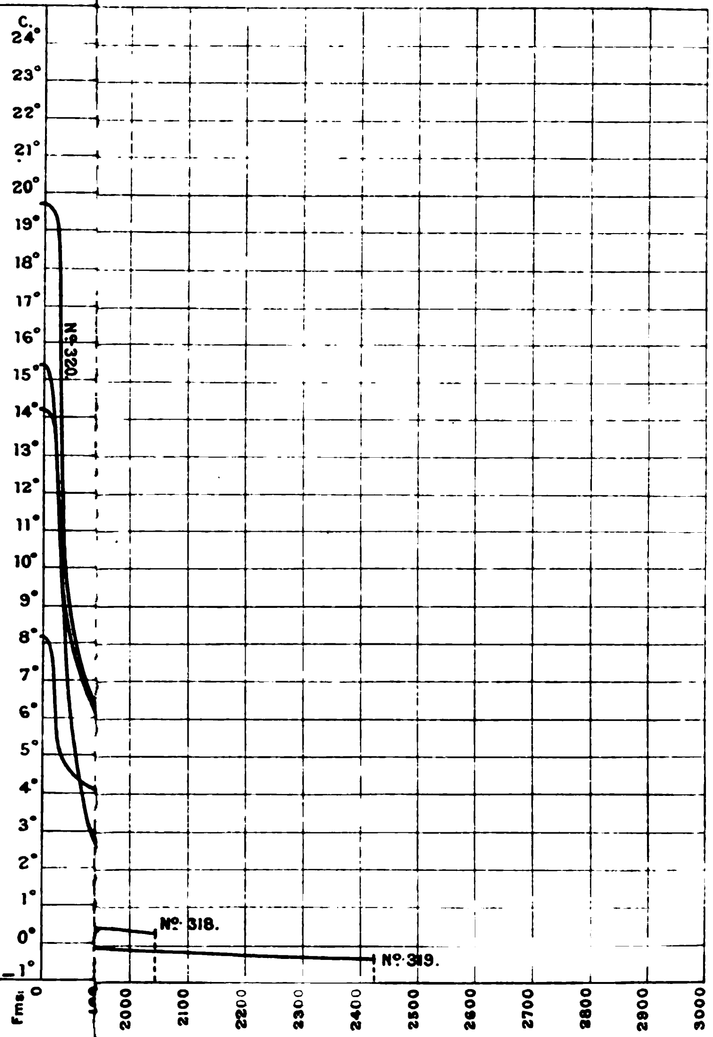


Malby & Sons, Lith.

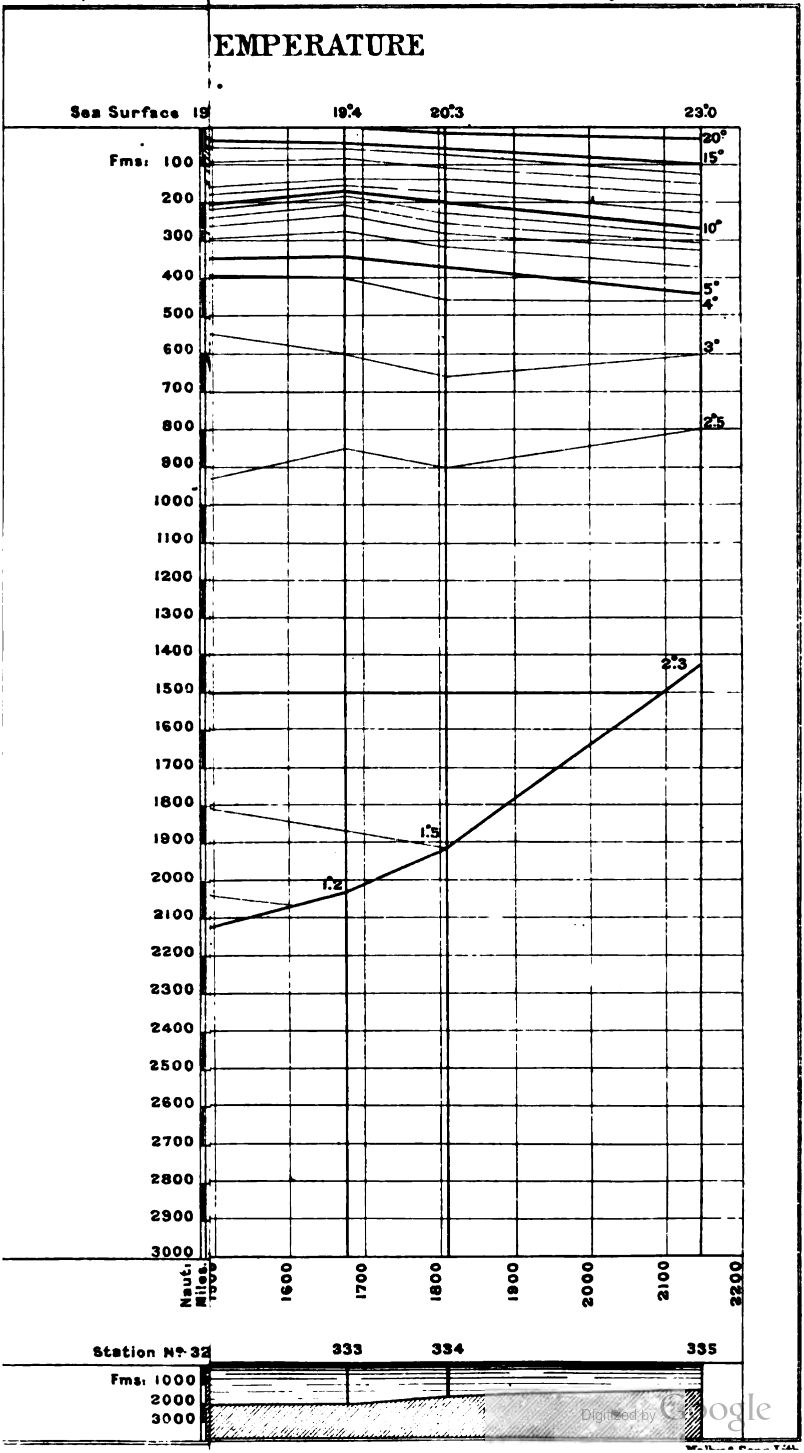
ERATURE


Sea Surface 9°.7
14°.7
21°.0
15°
10°
5°
4°
3°
2°.7
Fms. 100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
0 Naut. Miles.
900
1000
1100
FALKLAND Is.
LOBOS Is.
Station No. 316
320
Fms. 1000
2000
3000

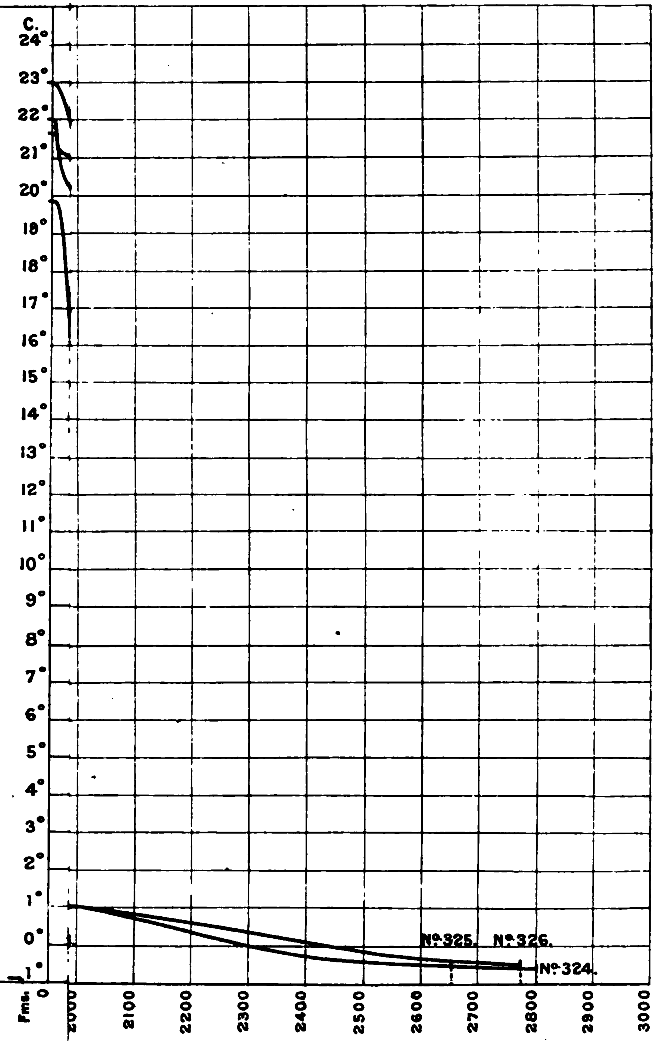
SOUNDINGS
E VIDEO.



Malby & Sons, L

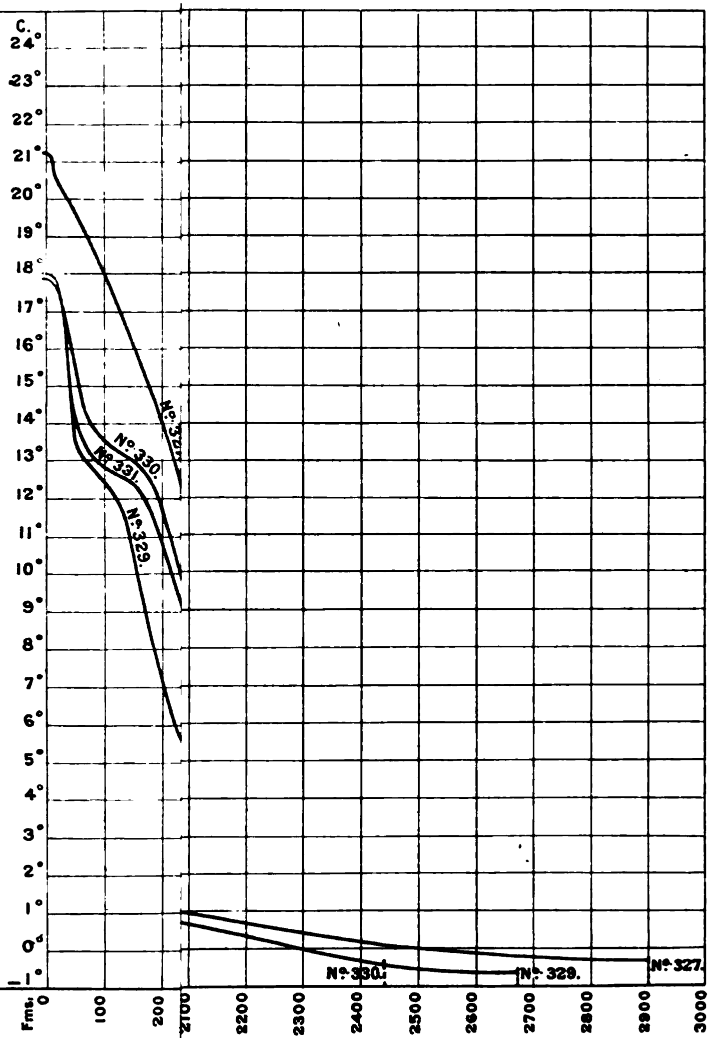

EMPERATURE
Sea Surface 19
19°.4
20°.3
23°.0
20°
15°
10°
5°
4°
3°
2°.5
2°.3
1°.5
1°.2
Fms: 100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
Naut. Miles.
1500
1600
1700
1800
1900
2000
2100
2200
Station No. 32
333
334
335
Fms: 1000
2000
3000

SOUNDINGS

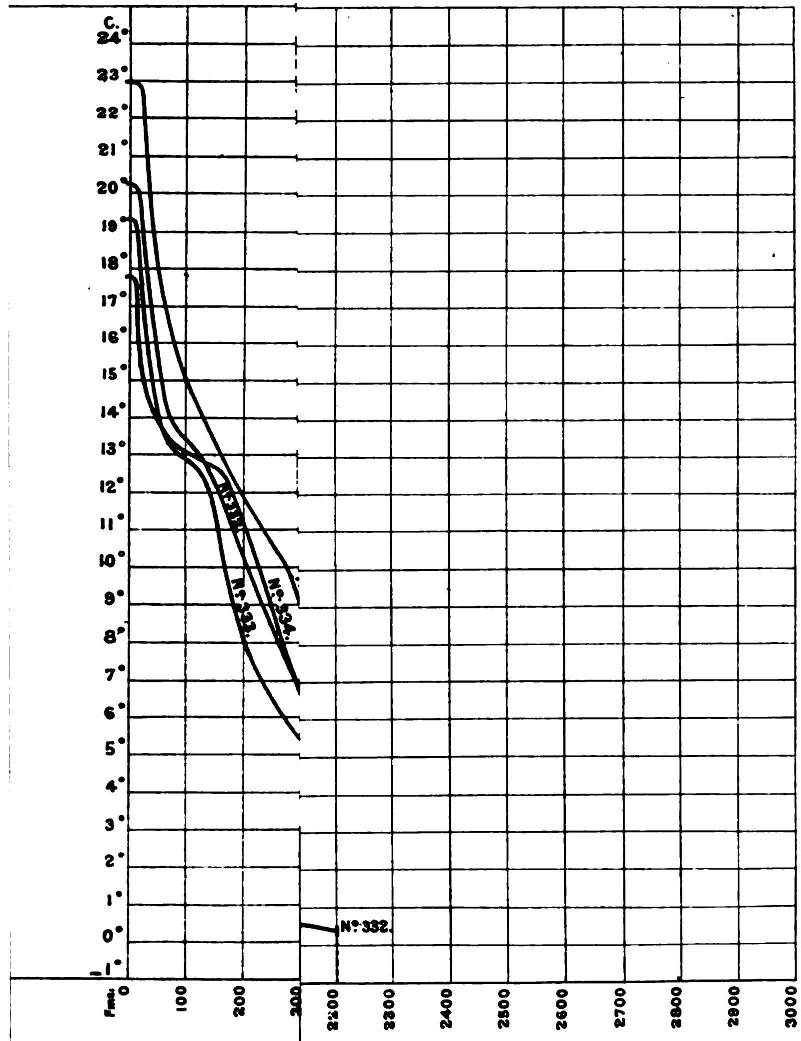


Malby & Sons, Lith.

S

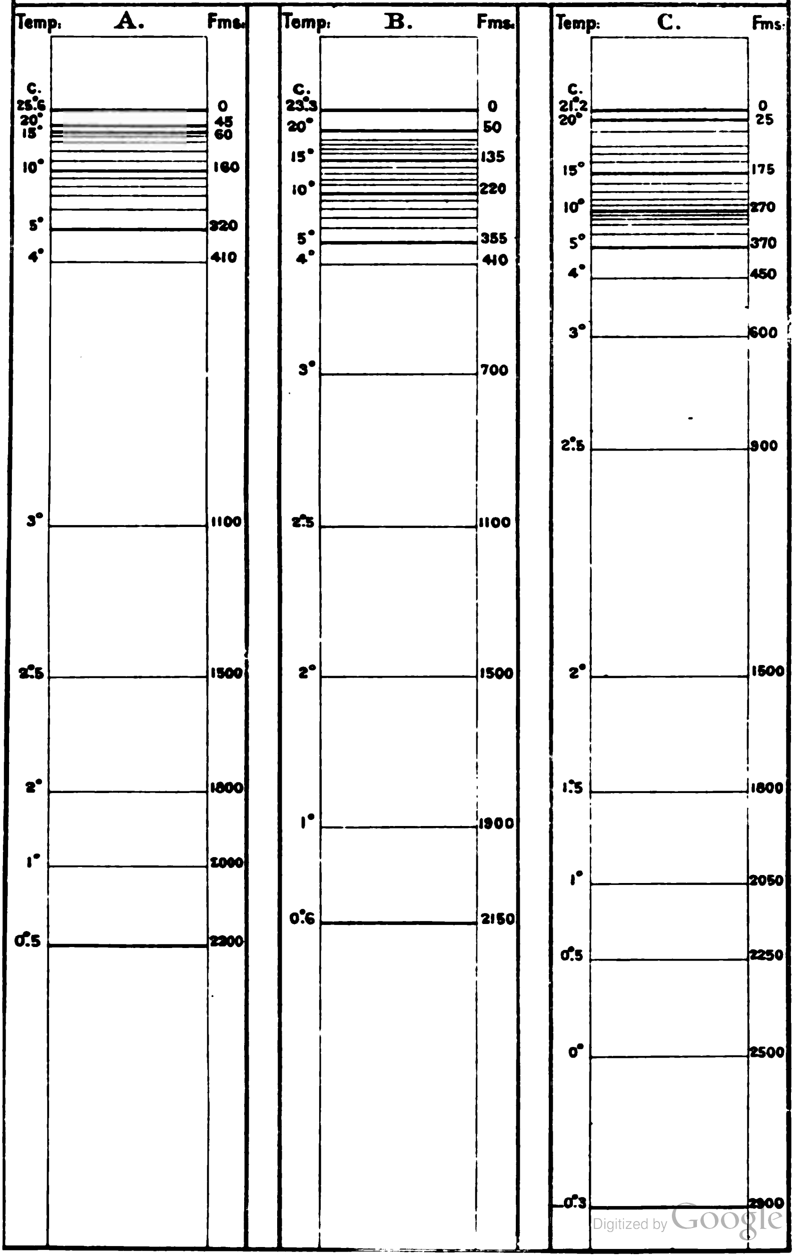


Malby & Sons, Lith.

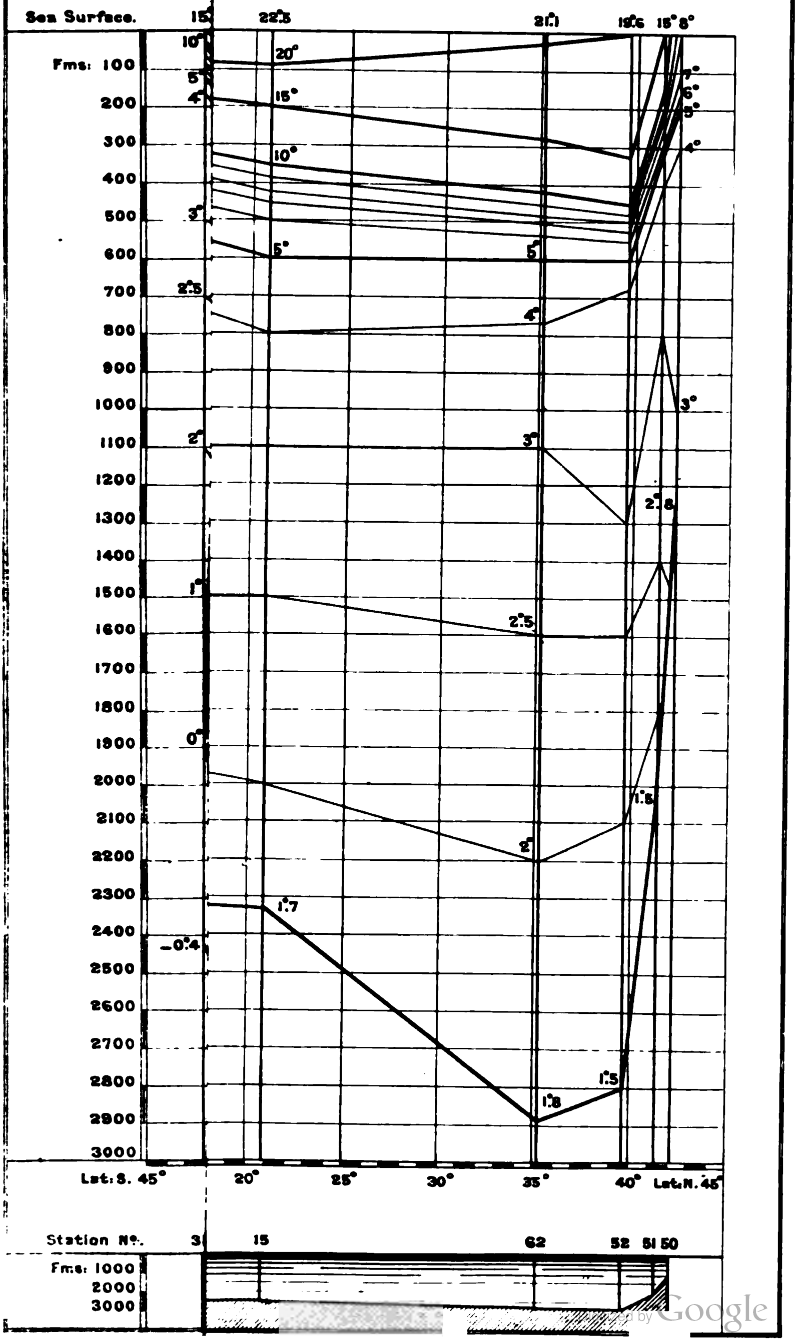

C.
24°
23°
22°
21°
20°
19°
18°
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
0°
-1°
Fms. 0
100
200
300
2200
2300
2400
2500
2600
2700
2800
2900
3000
Nº 317.
Nº 333.
Nº 334.
Nº 332.

Malby & Sc

DIAGRAM SHOWING THE VERTICAL DISTRIBUTION OF TEMPERATURE AT STATIONS (A) No. 112, (B) No. 129, (C) No. 327.

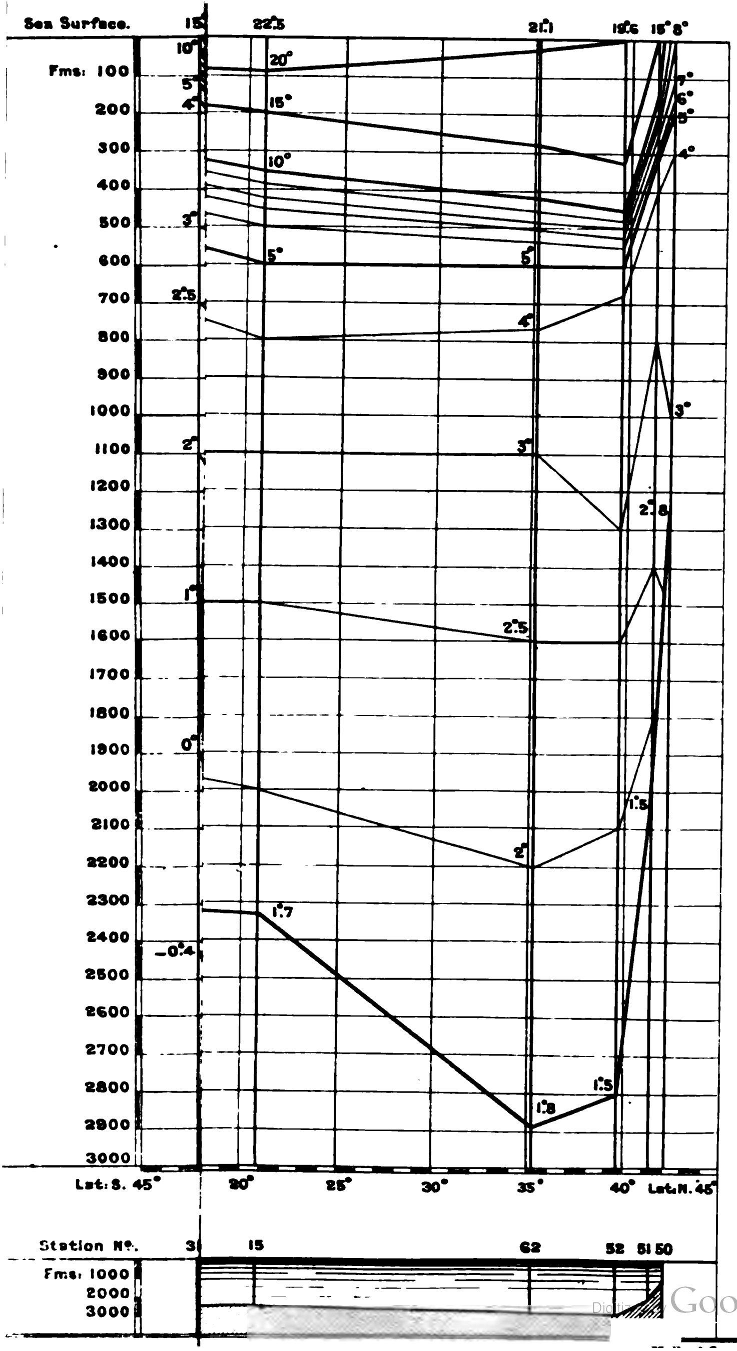


EMPERATURE


Sea Surface.
15°
22.5
21.1
19.6
15°
8°
Fms: 100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
10°
5°
4°
3°
2.5
2°
1°
0°
-0.4
20°
15°
10°
5°
5°
4°
3°
2.5
2°
1.7
1.8
1.5
1.5
2.8
7°
6°
5°
4°
3°
Lat: S. 45°
20°
25°
30°
35°
40°
Lat: N. 45°
Station No.
3
15
62
52
51
50
Fms: 1000
2000
3000

EMPERATURE

r.



INDEX TO VOL. XXIV.

ABERDARE (Rt. Hon. Lord), elected, 183; admitted, 276.
Adams (W. G.), Bakerian Lecture, on the forms of equipotential curves and surfaces and on lines of flow, 1.
—— on the action of light on tellurium and selenium, 163.
Address of the President, 72.
Admiralty, preliminary report to the Hydrographer of the, on some of the results of the cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso, 403, 463.
——, report to the Hydrographer of the, on the cruise of H.M.S. 'Challenger' from June to August 1875, 33.
—— report to the Hydrographer of the, on the voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a position in lat. 32° 24′ S., long. 13° 5′ W., 623.
Air and water, on the friction between, 441.
Alcyonarian *Heliopora cærulea*, on the structure and relations of the, with some account of the anatomy of a species of *Sarcophyton*, notes on the structure of species of the genera *Millepora*, *Pocillopora*, and *Stylaster*, and remarks on the affinities of certain Palæozoic corals, 59.
Alimentary canal, on the minute anatomy of the, 241.
Andrews (T.), Bakerian Lecture, on the gaseous state of matter, 455.
Animal mechanics, on some elementary principles in: No. VII. The law of fatigue, 42.
Anniversary Meeting, Nov. 30, 1875, 70.
Antedon rosaceus, on the structure, physiology, and development of, 211, 451.
Atmosphere, on the optical deportment of the, in reference to the phenomena of putrefaction and infection, 171.
——, on the refraction of sound by the, 164.
Attraction-meter, on an, and on determining the depth of the sea without the use of the sounding-line, 317.
Auditors, election of, 32; report of, 70.

Baber (E. C.), contributions to the minute anatomy of the thyroid gland of the dog, 240.
Bakerian Lecture, on the forms of equipotential curves and surfaces and on lines of flow, 1.
—— ——, on the gaseous state of matter, 455.
Balfour (F. M.) on the development of the spinal nerves in Elasmobranch fishes, 135.
Bar-magnets and conducting-wires, on some electro-magnetic rotations of, on their axes, 121.
Bate (C. S.) on the development of the crustacean embryo, and the variations of form exhibited in the larvæ of 38 genera of Podophthalmia, 375.
Batrachia, on the structure and development of the skull in the: Part II., 136.
Blood, on the production of glycosuria by the effect of oxygenated, on the liver, 51.
Bodies, on the compound nature of the line-spectra of elementary, 352.
Broun (J. A.) on the variations of the daily mean horizontal force of the earth's magnetism produced by the sun's rotation and the moon's synodical and tropical revolutions, 231.
Buchanan (J. Y.), preliminary report to Prof. W. Thomson on chemical and geological work done on board H.M.S. 'Challenger,' 388, 593.

Candidates for election, list of, March 2, 1876, 345.
Capello (J.) on the diurnal variations of the disturbances of the magnetic declination at Lisbon, 373.
Carnarvon (Earl of), admitted, 32.

Carpenter (W. B.) on the structure, physiology, and development of *Antedon rosaceus*, 211, 451.
'Challenger,' preliminary report to Prof. W. Thomson on chemical and geological work done on board H.M.S., 388, 593.
——, preliminary report to Prof. W. Thomson on Crustacea observed during the cruise of H.M.S., in the Southern Sea, 387, 585.
——, preliminary report to Prof. W. Thomson on observations made during the earlier part of the voyage of H.M.S., 387, 569.
——, preliminary report to Prof. W. Thomson on the true corals dredged by H.M.S., in deep water, between Dec. 30, 1870, and Aug. 31, 1875, 387, 544.
——, preliminary reports to Prof. W. Thomson on work done on board the, 387, 471.
——, report to the Hydrographer of the Admiralty on the cruise of H.M.S., from June to August 1875, 33.
——, report to the Hydrographer of the Admiralty on the voyage of the, from the Falkland Islands to Monte Video, and a position in lat. 32° 24' S., long. 13° 5' W., 623.
Chemical and geological work, preliminary report on, done on board H.M.S. 'Challenger,' 388, 593.
Cirripedia, on the development of *Lepas fascicularis* and the "*Archizoëa*" of, 129.
Colliery explosions, on the influence of coal-dust in, 354.
Collodion plate, on reversed photographs of the solar spectrum obtained on a, 186.
Conducting-wires and bar-magnets, on some electro-magnetic rotations of, on their axes, 121.
Copley medal awarded to August Wilhelm Hofmann, 89.
Corals, on the structure and relations of certain, 59.
——, on the true, dredged by H.M.S. 'Challenger,' 387, 544.
Corti, on the organ of, in mammals, 346.
Council, list of, 47, 94.
Crookes (W.), royal medal awarded to, 91.
——, on repulsion resulting from radiation: Part III., 276; Part IV., 279.
—— on the movement of the glass case of a radiometer, 409.
Crustacea, preliminary report on, observed during the cruise of H.M.S. 'Challenger' in the Southern Sea, 387, 585.
Crustacean embryo, on the development of the, and the variations of form exhibited in the larvæ of 38 genera of Podophthalmia, 375.
Currents, on instruments for recording the direction and velocity of, and the temperature of the water at different depths in the ocean, 321.
Curves and surfaces, on the forms of equipotential, and on lines of flow, 1.

Decapods, on the development of some pelagic, 132.
Decease of R. von Willemöes-Suhm, notice of the, 33.
Declination, magnetic dip, and horizontal force, results of the monthly observations of, made at the Kew Observatory from April 1869 to March 1875 inclusive, 232.
De la Rive (A. A.), obituary notice of, xxxvii.
De La Rue (W.) and Müller (H. W.) on the length of the spark from a battery of 600, 1200, 1800, and 2400 rod-chloride-of-silver cells, and some phenomena attending the discharge of 5640 cells, 167.
Delaunay (C. E.), obituary notice of, vii.
Depth of the sea, on determining the, without the use of the sounding-line, and on an attraction-meter, 317.
Differential equations of the first order, on the theory of the solution of a system of simultaneous partial, 337.
Direct-vision compound prism presented to the Society by Mr. Gassiot, 33.
Disraeli (Rt. Hon. B.), elected, 276.
Dog, contributions to the minute anatomy of the thyroid gland of the, 240.
Donation fund, account of grants from the, 102.

Earth's magnetism, on the variations of the daily mean horizontal force of the, produced by the sun's rotation and the moon's synodical and tropical revolutions, 231.
Elasmobranch fishes, on the development of the spinal nerves in, 135.
Electric sparks, on the length of, 167.
Electrolysis, experimental contributions to the theory of, 308.
Electro-magnetic rotation, an experiment on, 403.
——, rotations, on some, of bar-magnets and conducting-wires on their axes, 121.
Electromotive force, on certain cases of, sustained by the action of electrolytes on electrolytes, 183.
Electro-positive and electro-negative metals, on the replacement of, in a voltaic cell, 47.
Elementary bodies, on the compound nature of the line-spectra of, 352.
Ellery (R. L. J.), admitted, 32.
Embryo, on the development of the crus-

tacean, and the variations of form exhibited in the larvæ of 38 genera of Podophthalmia, 375.
Equation, mechanical integration of the general linear differential, of any order with variable coefficients, 271.
Equations, mechanical integration of the linear differential, of the second order with variable coefficients, 269.
—— of the first order, on the theory of the solution of a system of simultaneous non-linear partial differential, 337.
Equipotential curves and surfaces, on the forms of, and on lines of flow, 1.
Expansion of sea-water by heat, on the, 159.
Explosions, on the influence of coal-dust in colliery, 354.
Extract from the will of the late Sir C. Wheatstone, 32.

Falkland Islands to Monte Video &c., report to the Hydrographer of the Admiralty on the Voyage of the 'Challenger' from the, 623.
Fatigue, on the law of, 42.
Fellows deceased, 71; elected, 71; number of, 95.
Figures, on the number of, in the period of each reciprocal of a prime from 53,000 to 60,000, 392.
Financial statement, 96, 97.
Fishes, on the development of the spinal nerves in Elasmobranch, 135.
Force, electromotive, on certain cases of, sustained by the action of electrolytes on electrolytes, 183.
——, on the, caused by the communication of heat between a surface and a gas, and on a new photometer, 388.
——, on the nature of the, producing the motion of a body exposed to rays of heat and light, 391.
Formulæ of verification in the partition of numbers, 250.
Friction, on the, between air and water, 441.
Functions, on an instrument for calculating the product of two given, 266.

Galloway (W.) on the influence of coal-dust in colliery explosions, 354.
Gaseous state of matter, on the, 455.
Gassiot (J. P.), a direct-vision compound prism presented to the Society by, 33.
Geikie (J.), admitted, 32.
Geological and chemical work, preliminary report on, done on board H.M.S. 'Challenger,' 388, 593.
Gladstone (J. H.) and Tribe (A.) on the replacement of electro-positive by electro-negative metals in a voltaic cell, 47.
Glaisher (J. W. L.) on formulæ of verification in the partition of numbers, 250.
Glass case of a radiometer, on the movement of the, 409.
Glycosuria, on the poduction of, by the effect of oxygenated blood on the liver, 51.
Gore (G.) on some electro-magnetic rotations of bar-magnets and conducting-wires on their axes, 121.
Government grant, account of appropriation of the, 1875, 101.

Hanbury (D.), obituary notice of, ii.
Hansteen (C.), obituary notice of, v.
Haughton (S.) on some elementary principles in animal mechanics: No. VII. The law of fatigue, 42.
Hawaii and Valparaiso, on some of the results of the cruise of H.M.S. 'Challenger' between, 403, 463.
Heat and light, on the nature of the force producing the motion of a body exposed to rays of, 391.
——, on the expansion of sea-water by, 159.
——, on the force caused by the communication of, between a surface and a gas, and on a new photometer, 388.
Heliopora cærulea, on the structure and relations of the Alcyonarian, 59.
Hofmann (A. W.), Copley medal awarded to, 89.
Hopkinson (J.) on certain cases of electromotive force sustained by the action of electrolytes on electrolytes, 183.
—— on the residual charge of the Leyden jar, 407.
Horizontal force, magnetic dip, and declination, results of the monthly observations of, made at the Kew Observatory from April 1869 to March 1875 inclusive, 232.
—— force, on the variations of the daily mean, of the earth's magnetism produced by the sun's rotation and the moon's synodical and tropical revolutions, 231.
Hydrographer of the Admiralty, preliminary report to the, on some of the results of the cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso, 403, 463.
—— of the Admiralty, report to the, on the cruise of H.M.S. 'Challenger' from June to August 1875, 33.
—— of the Admiralty, report to the, on the voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a position in lat. 32° 24′ S., long. 13° 5′ W., 623.
Hyrax, on the placentation of, 151.

Infection and putrefaction, on the optical deportment of the atmosphere in reference to the phenomena of, 171.

Instrument, on an, for calculating $\left(\int\phi(x)\psi(x)dx\right)$, the integral of the product of two given functions, 266.
Instruments for measuring currents and temperature in the ocean, 321.
Integrating machine, on an, having a new kinematic principle, 262.

Jaundice, an inquiry into the cause of the slow pulse in, 442.
Jodrell (T. J. P.), letter to the President from, 316.
Jones (J. R.) on instruments for recording the direction and velocity of currents and the temperature of the water at different depths in the ocean, 321.

Kew Committee, report of the, 102.
—— ——, results of the monthly obserservations of magnetic dip, horizontal force, and declination made at the Kew Observatory from April 1869 to March 1875 inclusive, 232.
Key (T. H.), obituary notice of, x.
Kinematic principle, on an integrating machine having a new, 262.
Klein (E.), admitted, 32.

Lang (R. von), experiments on the friction between water and air, 441.
Lankester (E. R.), admitted, 32.
Lecture, the Bakerian, 1, 455.
Legg (J. W.), an inquiry into the cause of the slow pulse in jaundice, 442.
Lemurs, on the placentation of the, 409.
Lepas fascicularis, on the development of, and the "*Archizoëa*" of Cirripedia, 129.
Leyden jar, on the residual charge of the, 407.
Liebig (J.), obituary notice of, xxvii.
Light and heat, on the nature of the force producing the motion of a body exposed to rays of, 391.
——, on the action of, on tellurium and selenium, 163.
Line-spectra of elementary bodies, on the compound nature of the, 352.
Linear differential equation of any order, mechanical integration of the general, with variable coefficients, 271.
—— —— equations of the second order, mechanical integration of the, with variable coefficients, 269.
Liquids, researches upon the specific volumes of: Part II., 283; Part III., 298.
Lisbon, on the diurnal variations of the disturbances of the magnetic declination at, 373.
Liver, on the production of glycosuria by the effect of oxygenated blood on the, 51.
Lockyer (J. N.), preliminary note on the compound nature of the line-spectra of elementary bodies, 352.
Locomotor system of Medusæ, on the, 143.
Logan (Sir W. E.), obituary notice of, i.

Machine, on an integrating, having a new kinematic principle, 262.
Magnetic declination, on the diurnal variations of the disturbances of the, at Lisbon, 373.
—— dip, horizontal force, and declination, results of the monthly observations of, made at the Kew Observatory from April 1869 to March 1875 inclusive, 232.
Mammalian ovum, description of a, in an early condition of development, 399.
Mammals, on the organ of Corti in, 346.
Matter, on the gaseous state of, 455.
Mechanics, on some elementary principles in animal: No. VII. The law of fatigue, 42.
Medals, presentation of the, 89.
Medusæ, on the locomotor system of, 143.
Meeting, anniversary, November 30, 1875, 70.
Meldrum (C.) on a secular variation in the rainfall in connexion with the secular variation in amount of sunspots, 379.
Metals, on the replacement of electropositive by electro-negative, in a voltaic cell, 47.
Meteorological Committee, report of the, to the President and Council of the Royal Society on the work done in the Meteorological Office since their appointment in 1866 to Dec. 31, 1875, 189.
Millepora, on the structure of a species of, occurring at Tahiti, 448.
——, *Pocillopora*, and *Stylaster*, on the structure of species of the genera, 59.
Minute anatomy, on the, of the alimentary canal, 241.
Monte Video, report to the Hydrographer of the Admiralty on the voyage of the 'Challenger' from the Falkland Islands to, 623.
Moseley (H. N.) on the structure and relations of the Alcyonarian *Heliopora cærulea*, with some account of the anatomy of a species of *Sarcophyton*, notes on the structure of species of the genera *Millepora*, *Pocillopora*, and *Stylaster*, and remarks on the affinities of certain Palæozoic corals, 59.
—— on the structure of a species of *Millepora* occurring at Tahiti, Society Islands, 448.
——, preliminary report to Prof. W. Thomson on the true corals dredged by H.M.S. 'Challenger,' in deep water,

between the dates Dec. 30, 1870, and Aug. 31, 1875, 387, 544.
Müller (H. W.) and De La Rue (W.) on the length of the spark from a battery of 600, 1200, 1800, and 2400 rod-chloride-of-silver cells, and some phenomena attending the discharge of 5640 cells, 167.
Murray (J.), preliminary reports to Prof. W. Thomson on work done on board the 'Challenger,' 387, 471.

Nanson (E. J.) on the theory of the solution of a system of simultaneous non-linear partial differential equations of the first order, 337.
Newall (R. S.), admitted, 32.
Newton's rings, on a new refractometer for measuring the mean refractive index of plates of glass and lenses by the employment of, 393.
Non-linear partial differential equations of the first order, on the theory of the solution of, 337.
Numbers, formulæ of verification in the partition of, 250.

Obituary notices of Fellows deceased:—
  Sir William Edmond Logan, i.
  Daniel Hanbury, ii.
  Gustav Rose, iii.
  Christopher Hansteen, v.
  Charles Eugène Delaunay, vii.
  Thomas Hewitt Key, x.
  Sir Charles Wheatstone, xvi.
  Justus Liebig, xxvii.
  Auguste Arthur de la Rive, xxxvii.
Observations, preliminary report on, made during the earlier part of the voyage of H.M.S. 'Challenger,' 387, 569.
Ocean, on instruments for recording the direction and velocity of currents and the temperature of the water at different depths in the, 321.
Oceanic deposits examined on board H.M.S. 'Challenger,' preliminary report on, 471.
Oldham (T.), royal medal awarded to, 93.
Organ of Corti in mammals, on the, 346.
Ovum, description of a mammalian, in an early condition of development, 399.
Owen (P. C.), letter to the President from, 315.
Oxygenated blood, on the production of glycosuria by the effect of, on the liver, 51.

Palæozoic corals, on the affinities of certain, 59.
Parker (W. K.) on the structure and development of the skull in the Batrachia: Part II., 136.
Partition of numbers, formulæ of verification in the, 250.
Pavy (F. W.) on the production of glycosuria by the effect of oxygenated blood on the liver, 51.
Pelagic Decapods, on the development of some, 132.
Photographs, on reversed, of the solar spectrum beyond the red, obtained on a collodion plate, 186.
Photometer, on a new, and on the force caused by the communication of heat between a surface and a gas, 388.
Physiological action of vanadium, on the, 40.
Physiology, structure, and development of *Antedon rosaceus*, on the, 211, 451.
Placentation of *Hyrax*, on the, 151.
—— of the lemurs, on the, 409.
Pocillopora, *Millepora*, and *Stylaster*, on the structure of species of the genera, 59.
Podophthalmia, on the development of the crustacean embryo, and the variations of form exhibited in the larvæ of 38 genera of, 375.
Poison-fangs of snakes, on the development and succession of the, 259.
Presentation of the medals, 89.
Presents, list of, 115, 155, 244, 330, 410, 459.
President, letter to the, from T. J. P. Jodrell, 316.
——, letter to the, from P. C. Owen, 315.
President's Address, 72.
Priestley (J.) on the physiological action of vanadium, 40.
Prime, on the number of figures in the period of each reciprocal of a, from 53,000 to 60,000, 392.
Prism, a direct-vision compound, presented to the Society by J. P. Gassiot, 33.
Pritchard (U.) on the organ of Corti in mammals, 346.
Pulse, an inquiry into the cause of the slow, in jaundice, 442.
Putrefaction and infection, on the optical deportment of the atmosphere in reference to the phenomena of, 171.

Radiation, on repulsion resulting from: Part III., 276; Part IV., 279.
Radiometer, on the movement of the glass case of a, 409.
Rainfall, on a secular variation in the, in connexion with the secular variation in amount of sun-spots, 379.
Refraction of sound, on the, by the atmosphere, 164.
Refractometer, on a new, for measuring the mean refractive index of plates of glass and lenses by the employment of Newton's rings, 393.

Report of Auditors, 70.
—— of the Meteorological Committee to the President and Council of the Royal Society on the work done in the Meteorological Office since their appointment in 1866 to Dec. 31, 1875, 189.
Reports from the 'Challenger,' 463.
Repulsion, on, resulting from radiation: Part III., 276; Part IV., 279.
Residual charge, on the, of the Leyden jar, 407.
Reynolds (O.) on the force caused by the communication of heat between a surface and a gas, and on a new photometer, 388.
—— on the refraction of sound by the atmosphere, 164.
Romanes (G. J.), preliminary observations on the locomotor system of Medusæ, 143.
Rose (Sir G.), obituary notice of, iii.
Rotation, an experiment on electro-magnetic, 403.
Royal medal awarded to W. Crookes and T. Oldham, 91, 93.
Royston-Pigott (G. W.) on a new refractometer for measuring the mean refractive index of plates of glass and lenses by the employment of Newton's rings, 393.
Rücker (A. W.) and Thorpe (T. E.) on the expansion of sea-water by heat, 159.

Sarcophyton, on the anatomy of a species of, 59.
Schäfer (E. A.), description of a mammalian ovum in an early condition of development, 399.
Schuster (A.) on the nature of the force producing the motion of a body exposed to rays of heat and light, 391.
Sclater-Booth (Rt. Hon. G.), elected, 183; admitted, 276.
Sea, on determining the depth of the, without the use of the sounding-line, and on an attraction-meter, 317.
Sea-water, on the expansion of, by heat, 159.
Selenium and tellurium, on the action of light on, 163.
Shanks (W.) on the number of figures in the period of each reciprocal of a prime from 53,000 to 60,000, 392.
Siemens (C. W.) on determining the depth of the sea without the use of the sounding-line, and on an attraction-meter, 317.
Skull, on the structure and development of the, in the Batrachia: Part II., 136
Snakes, on the development and succession of the poison-fangs of, 259.
Solar spectrum, on reversed photographs of the, beyond the red, obtained on a collodion plate, 186.
Sound, on the refraction of, by the atmosphere, 164.
Sounding-line, on determining the depth of the sea without the use of the, 317.
Southern Sea, preliminary report on Crustacea observed during the cruise of H.M.S. 'Challenger' in the, 387, 585.
Spark, on the length of the, from a battery of 600, 1200, 1800, and 2400 rod-chloride-of-silver cells, and some phenomena attending the discharge of 5640 cells, 167.
Specific volumes of liquids, researches upon the: Part II., 182; Part III., 298.
Spinal nerves, on the development of the, in Elasmobranch fishes, 135.
Spottiswoode (W.), an experiment on electro-magnetic rotation, 403.
Stokes (G. G.), letter from, to J. N. Lockyer, 352.
Stylaster, *Millepora*, and *Pocillopora*, on the structure of species of the genera, 59.
Sun-spots, on a secular variation in the rainfall in connexion with the secular variation in amount of, 379.
Surface organisms examined on board H.M.S. 'Challenger,' preliminary report on some, 532.
System, on the locomotor, of the Medusæ, 143.

Tahiti, on the structure of a species of *Millepora* occurring at, 448.
Tait (L.), preliminary note on the anatomy of the umbilical cord, 417.
Tellurium and selenium, on the action of light on, 163.
Theory of electrolysis, experimental contributions to the, 308.
—— of the solution of a system of simultaneous non-linear partial differential equations of the first order, on the, 337.
Thomson (C. W.), preliminary report to the Hydrographer of the Admiralty on some of the results of the cruise of H.M.S. 'Challenger' between Hawaii and Valparaiso, 403, 463.
——, preliminary report to, on chemical and geological work done on board H.M.S. 'Challenger,' 388, 593.
——, preliminary report to, on the true corals dredged by H.M.S. 'Challenger,' in deep water, between Dec. 30, 1870, and Aug. 31, 1875, 387, 544.
——, preliminary report to, on Crustacea observed during the cruise of H.M.S. 'Challenger' in the Southern Sea, 387, 585.
——, preliminary report to, on observations made during the earlier part of

the voyage of H.M.S. 'Challenger,' 387, 569.
Thomson (C. W.), preliminary reports to, on work done on board the 'Challenger,' 387, 471.
——, report to the Hydrographer of the Admiralty on the cruise of H.M.S. 'Challenger' from June to August 1875, 33.
——, report to the Hydrographer of the Admiralty on the voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a position in lat. 32° 24′ S., long. 13° 5′ W., 623.
Thomson (J.) on an integrating machine having a new kinematic principle, 262.
Thomson (Sir W.), mechanical integration of the general linear differential equation of any order with variable coefficients, 271.
——, mechanical integration of the linear differential equations of the second order with variable coefficients, 269.
——, on an instrument for calculating $\left(\int\phi(x)\psi(x)dx\right)$, the integral of the product of two given functions, 266.
Thorpe (T. E.), researches upon the specific volumes of liquids: Part II., 283; Part III., 298.
—— and Rücker (A. W.) on the expansion of sea-water by heat, 159.
Thyroid gland of the dog, contributions to the minute anatomy of the, 240.
Tomes (C. S.) on the development and succession of the poison-fangs of snakes, 259.
Tribe (A.), experimental contributions to the theory of electrolysis, 308.
—— and Gladstone (J. H.) on the replacement of electro-positive by electro-negative metals in a voltaic cell, 47.
Trust funds, 98–100.
Turner (W.) on the placentation of *Hyrax*, 151.
—— on the placentation of the lemurs, 409.
Tyndall (J.) on the optical deportment of the atmosphere in reference to the phenomena of putrefaction and infection, 171.

Umbilical cord, preliminary note on the anatomy of the, 417.

Valparaiso and Hawaii, on some of the results of the cruise of H.M.S. 'Challenger' between, 403, 463.
Vanadium, on the physiological action of, 40.
Variable coefficients, mechanical integration of the general linear differential equation of any order with, 271.
—— ——, mechanical integration of the linear differential equations of the second order with, 269.
Vertebrates, preliminary report on, collected by H.M.S. 'Challenger,' 537.
Vice-Presidents appointed, 121.
Voltaic cell, on the replacement of electro-positive by electro-negative metals in a, 47.
Volumes of liquids, researches upon the, specific: Part II., 283; Part III., 298.

Water and air, on the friction between, 441.
Waterhouse (J.) on reversed photographs of the solar spectrum beyond the red, obtained on a collodion plate, 186.
Watney (H. A.) on the minute anatomy of the alimentary canal, 241.
Wheatstone (Sir C.), extract from the will of the late, 32.
——, obituary notice of, xvi.
Willemöes-Suhm (R. von), notice of the decease of, 33.
—— on the development of *Lepas fascicularis* and the "*Archizoëa*" of Cirripedia, 129.
——, preliminary remarks on the development of some pelagic Decapods, 132.
——, preliminary report to Prof. W. Thomson on Crustacea observed during the cruise of H.M.S. 'Challenger' in the Southern Sea, 387, 585.
——, preliminary report to Prof. W. Thomson on observations made during the earlier part of the voyage of H.M.S. 'Challenger,' 387, 569.
Work done on board the 'Challenger,' preliminary reports on, 387, 471.

END OF THE TWENTY-FOURTH VOLUME.

PRINTED BY TAYLOR AND FRANCIS,
RED LION COURT, FLEET STREET.